FIG.1

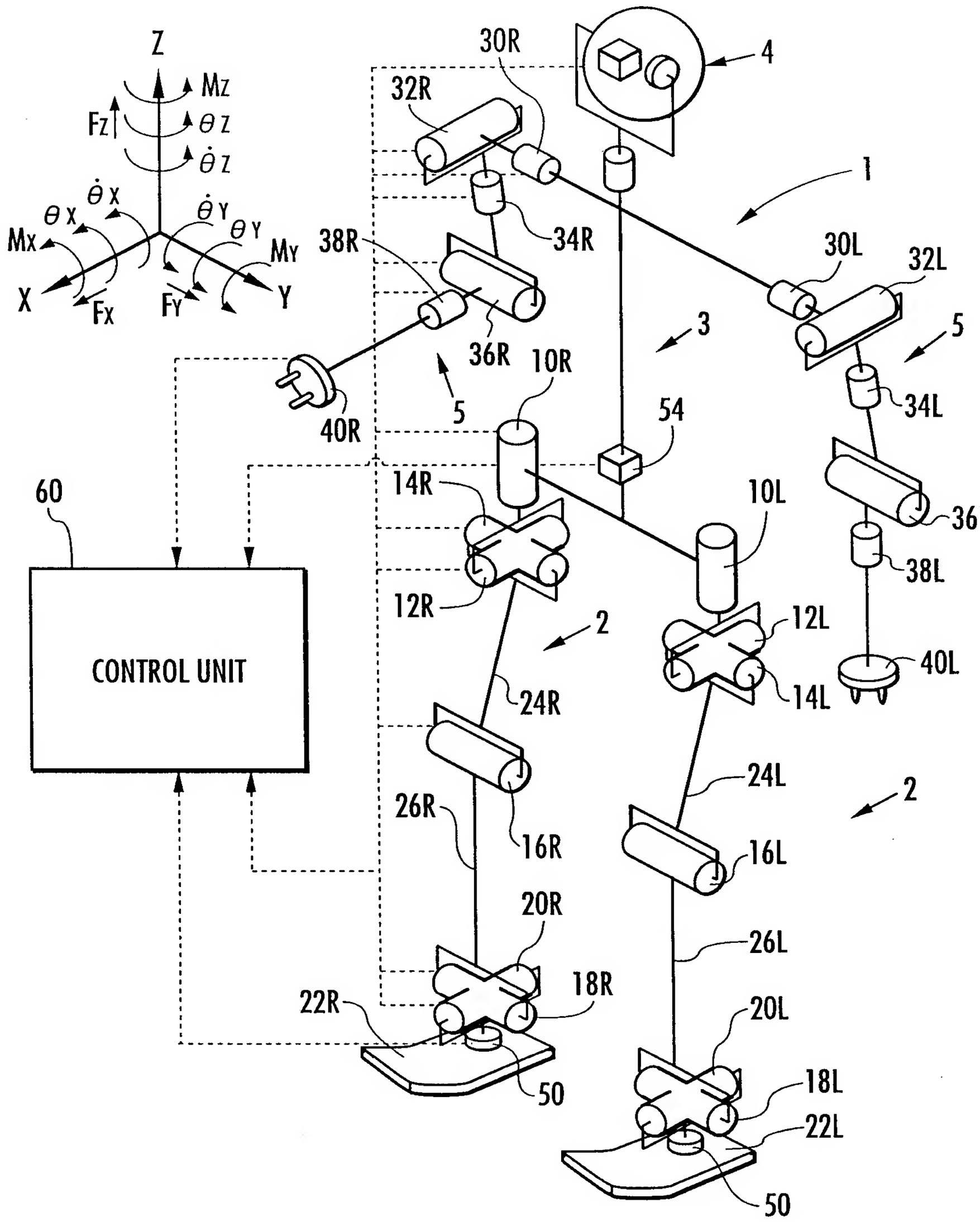

Z
Mz
Fz
θz
θ̇z
θ̇x
θx
θ̇y
θy
Mx
My
X
Y
Fx
Fy
30R
32R
4
1
34R
38R
30L
32L
3
5
36R
10R
34L
40R
5
54
60
14R
10L
36L
38L
CONTROL UNIT
12R
2
12L
40L
24R
14L
24L
2
26R
16R
16L
20R
26L
18R
22R
20L
18L
22L
50
50

FIG.2

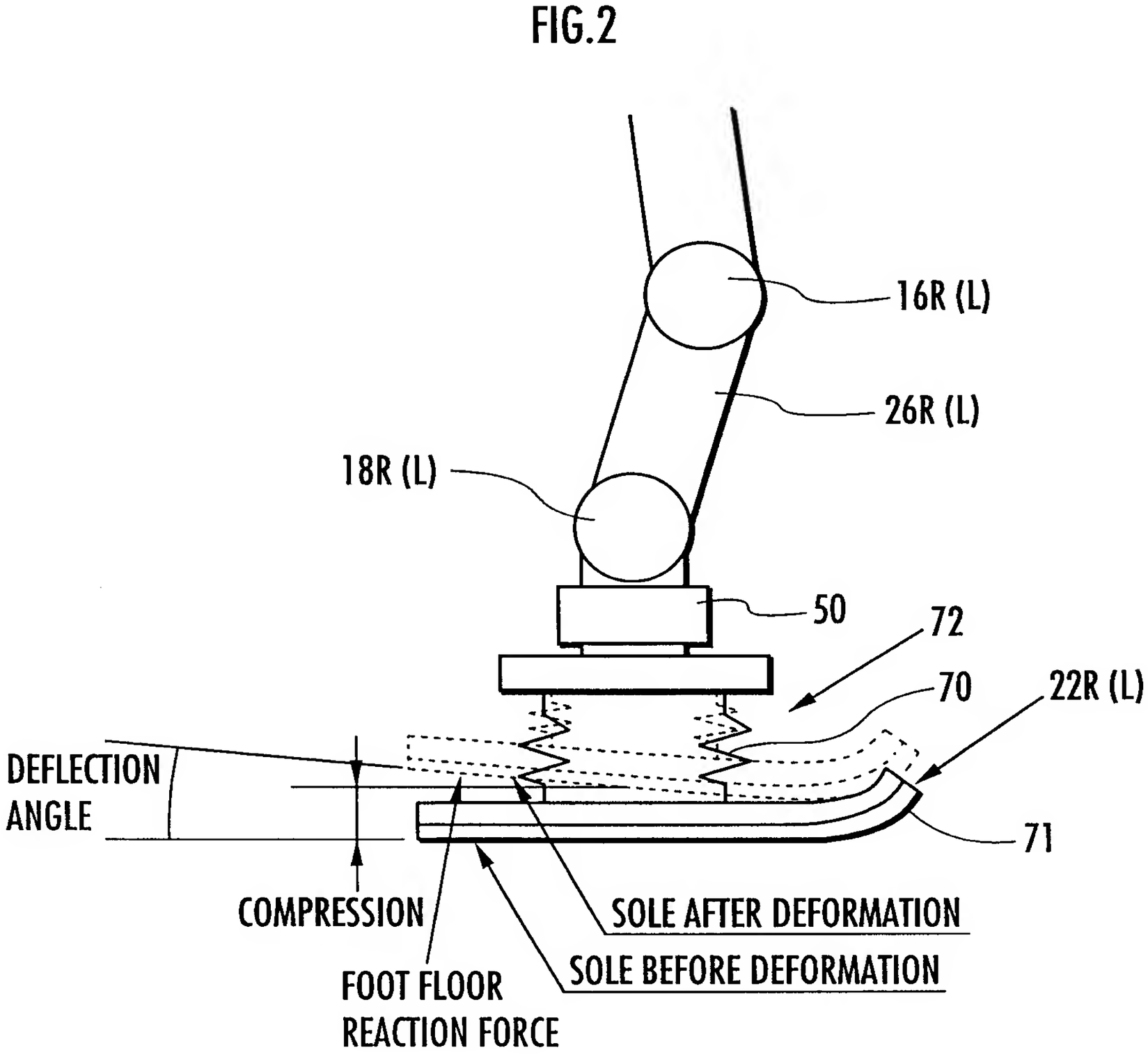

16R (L)
26R (L)
18R (L)
50
72
70
22R (L)
DEFLECTION ANGLE
71
COMPRESSION
SOLE AFTER DEFORMATION
SOLE BEFORE DEFORMATION
FOOT FLOOR
REACTION FORCE

FIG.3

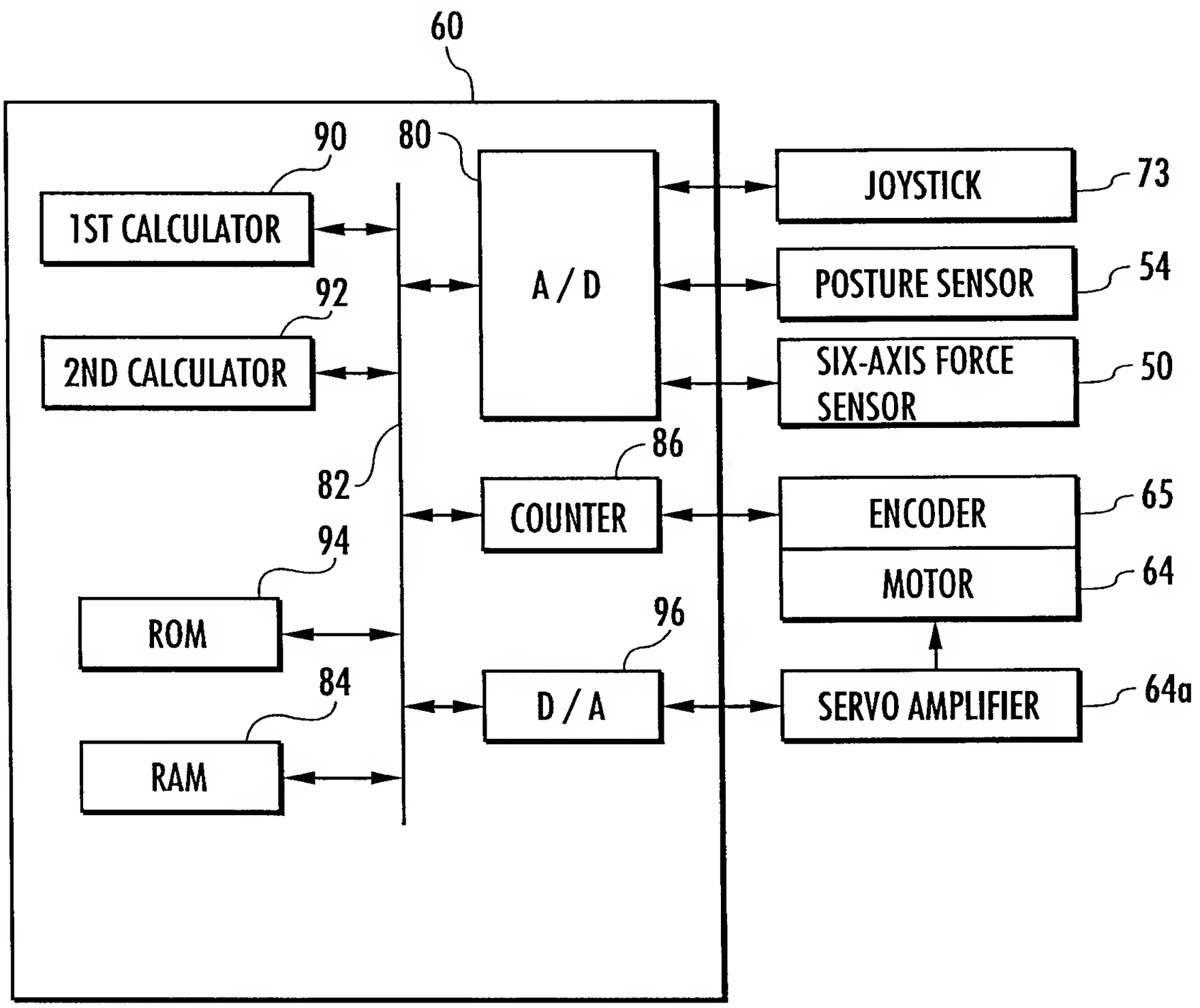

60
90
80
1ST CALCULATOR
A / D
JOYSTICK
73
POSTURE SENSOR
54
92
2ND CALCULATOR
SIX-AXIS FORCE SENSOR
50
82
86
COUNTER
ENCODER
65
MOTOR
64
94
ROM
96
84
D / A
SERVO AMPLIFIER
64a
RAM

FIG.4

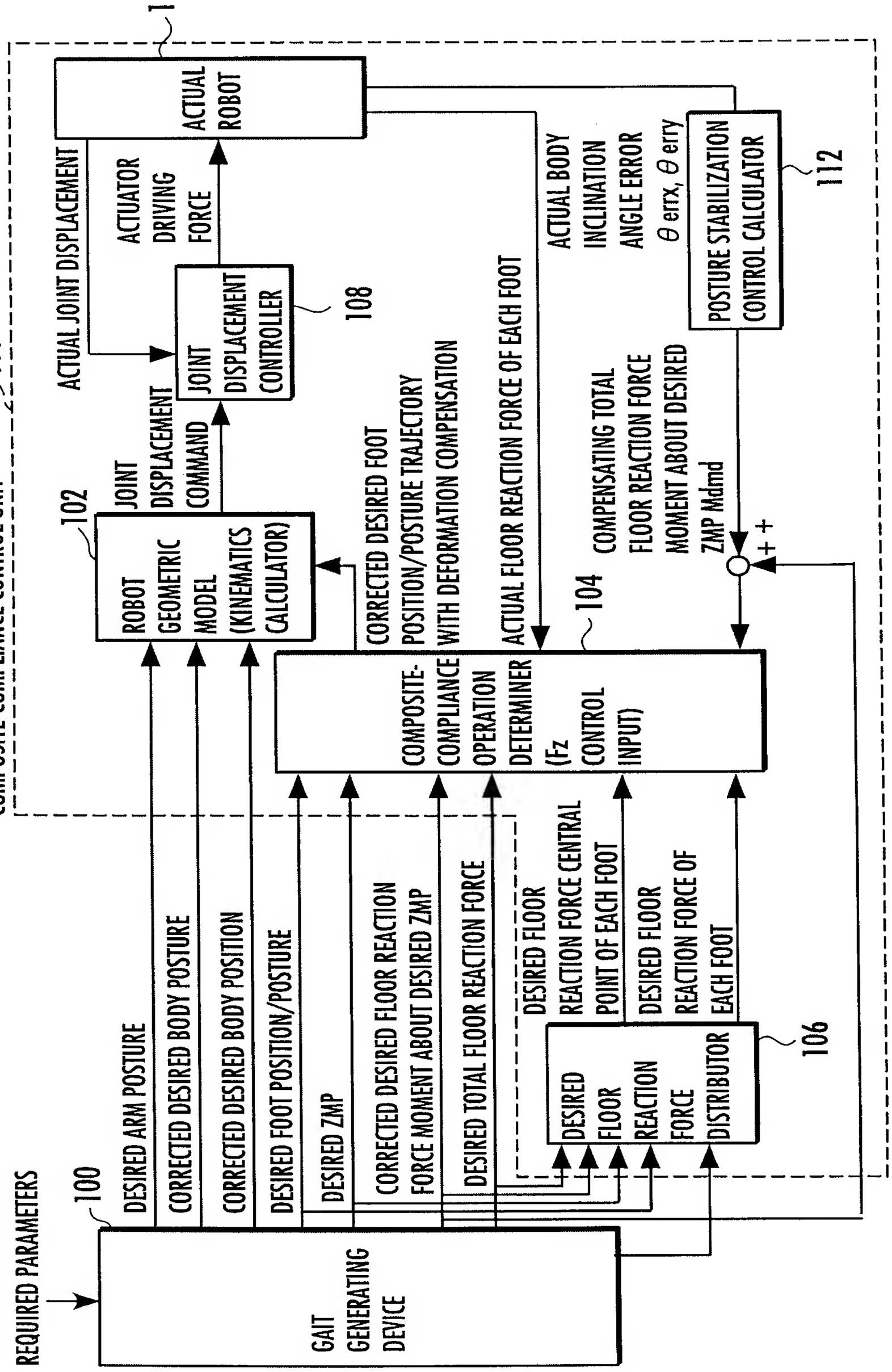

REQUIRED PARAMETERS
100
GAIT GENERATING DEVICE
DESIRED ARM POSTURE
CORRECTED DESIRED BODY POSTURE
CORRECTED DESIRED BODY POSITION
DESIRED FOOT POSITION/POSTURE
DESIRED ZMP
CORRECTED DESIRED FLOOR REACTION FORCE MOMENT ABOUT DESIRED ZMP
DESIRED TOTAL FLOOR REACTION FORCE
DESIRED FLOOR REACTION FORCE CENTRAL POINT OF EACH FOOT
DESIRED FLOOR REACTION FORCE OF EACH FOOT
DESIRED FLOOR REACTION FORCE DISTRIBUTOR
106
COMPOSITE-COMPLIANCE CONTROL UNIT
101
ROBOT GEOMETRIC MODEL (KINEMATICS CALCULATOR)
102
JOINT DISPLACEMENT COMMAND
CORRECTED DESIRED FOOT POSITION/POSTURE TRAJECTORY WITH DEFORMATION COMPENSATION
ACTUAL FLOOR REACTION FORCE OF EACH FOOT
COMPOSITE-COMPLIANCE OPERATION DETERMINER (Fz CONTROL INPUT)
104
COMPENSATING TOTAL FLOOR REACTION FORCE MOMENT ABOUT DESIRED ZMP Mdmd
+ +
JOINT DISPLACEMENT CONTROLLER
108
ACTUAL JOINT DISPLACEMENT
ACTUATOR DRIVING FORCE
ACTUAL ROBOT
1
ACTUAL BODY INCLINATION ANGLE ERROR
θ errx, θ erry
POSTURE STABILIZATION CONTROL CALCULATOR
112

FIG.5

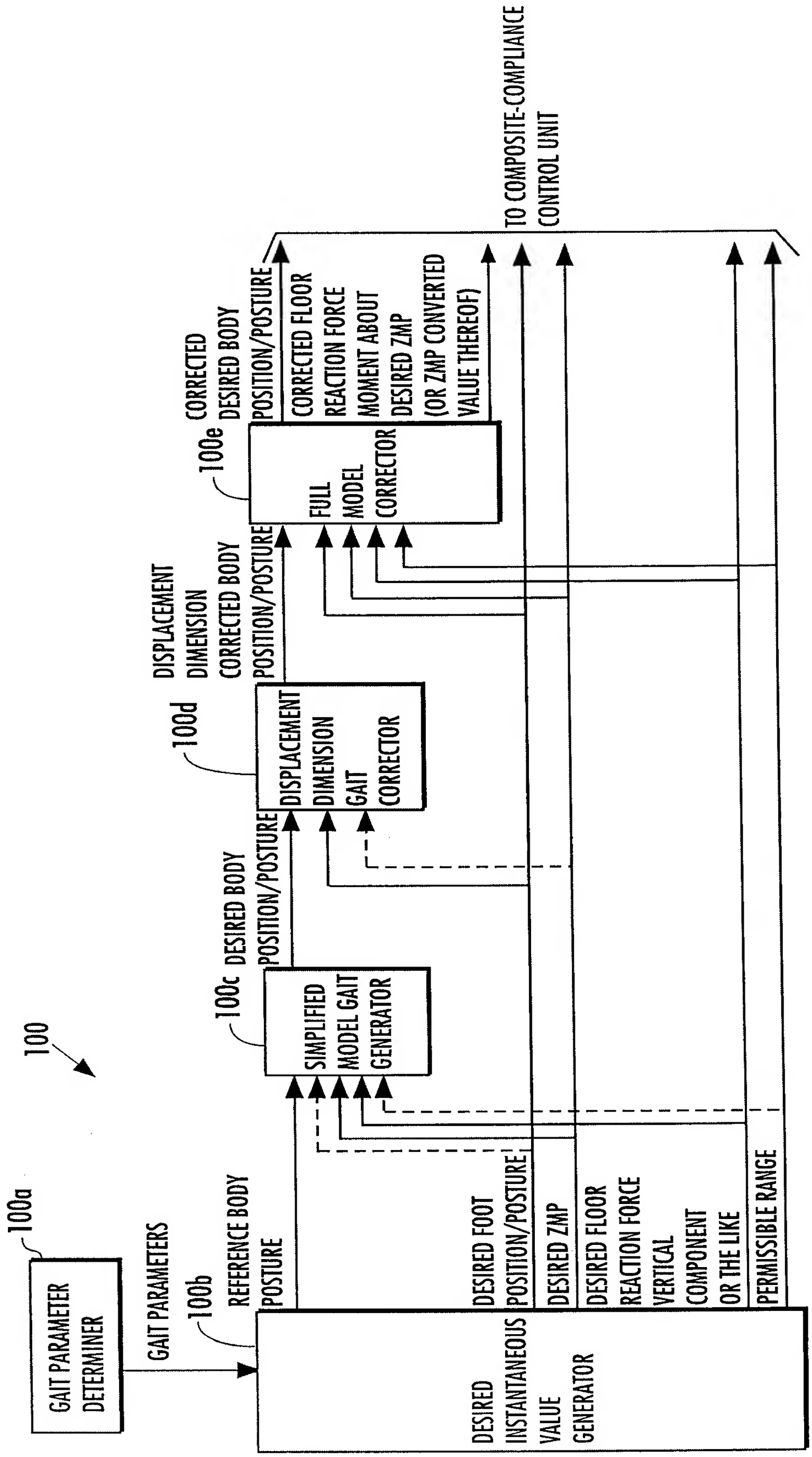

100
100a
GAIT PARAMETER DETERMINER
GAIT PARAMETERS
100b
REFERENCE BODY POSTURE
DESIRED INSTANTANEOUS VALUE GENERATOR
DESIRED FOOT POSITION/POSTURE
DESIRED ZMP
DESIRED FLOOR REACTION FORCE VERTICAL COMPONENT OR THE LIKE
PERMISSIBLE RANGE
100c
SIMPLIFIED MODEL GAIT GENERATOR
DESIRED BODY POSITION/POSTURE
100d
DISPLACEMENT DIMENSION GAIT CORRECTOR
DISPLACEMENT DIMENSION CORRECTED BODY POSITION/POSTURE
100e
FULL MODEL CORRECTOR
CORRECTED DESIRED BODY POSITION/POSTURE
CORRECTED FLOOR REACTION FORCE MOMENT ABOUT DESIRED ZMP (OR ZMP CONVERTED VALUE THEREOF)
TO COMPOSITE-COMPLIANCE CONTROL UNIT

FIG.6

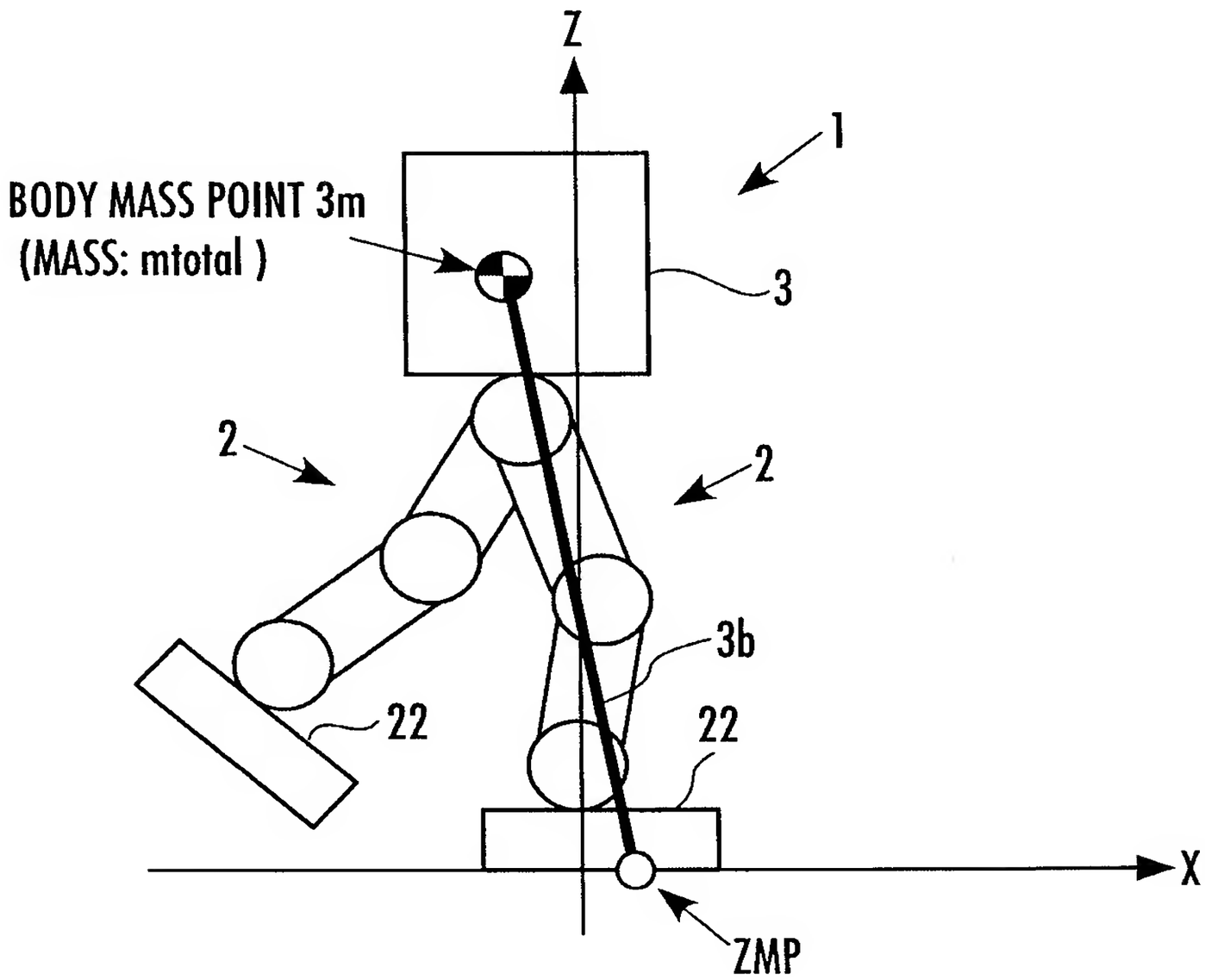


FIG.7(a)

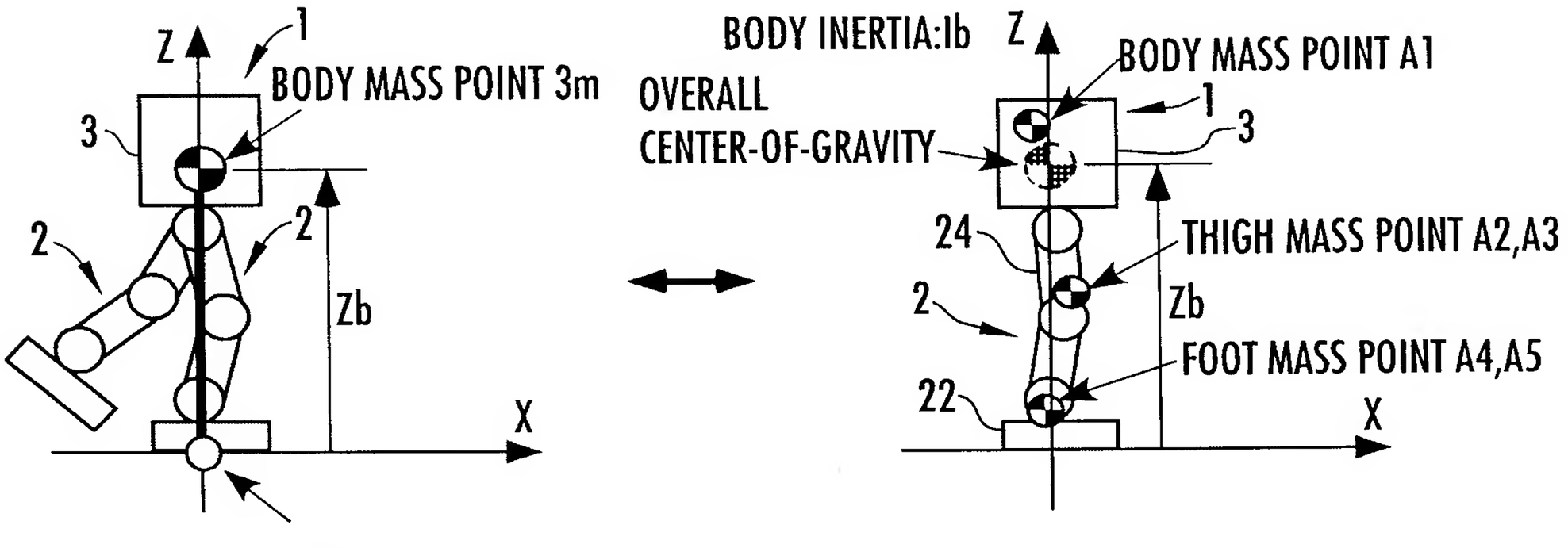


FIG.7(b)

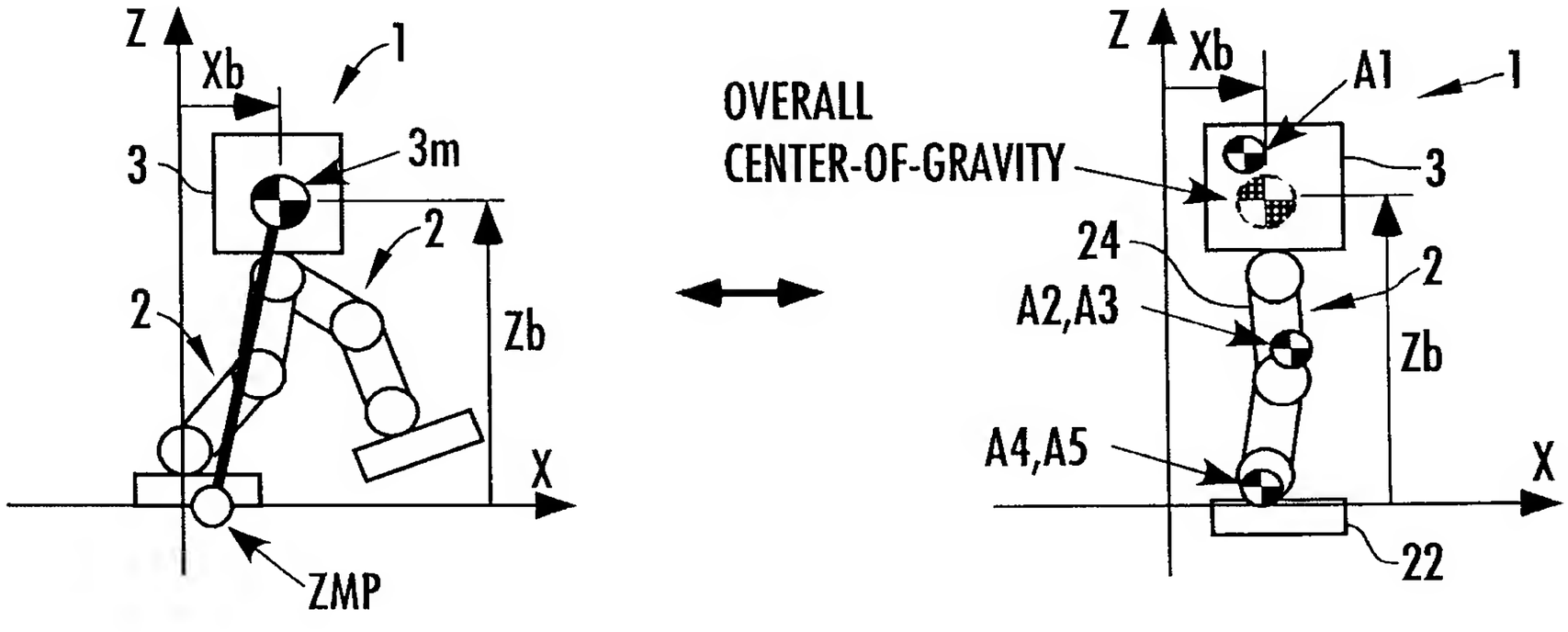


FIG.7(c)

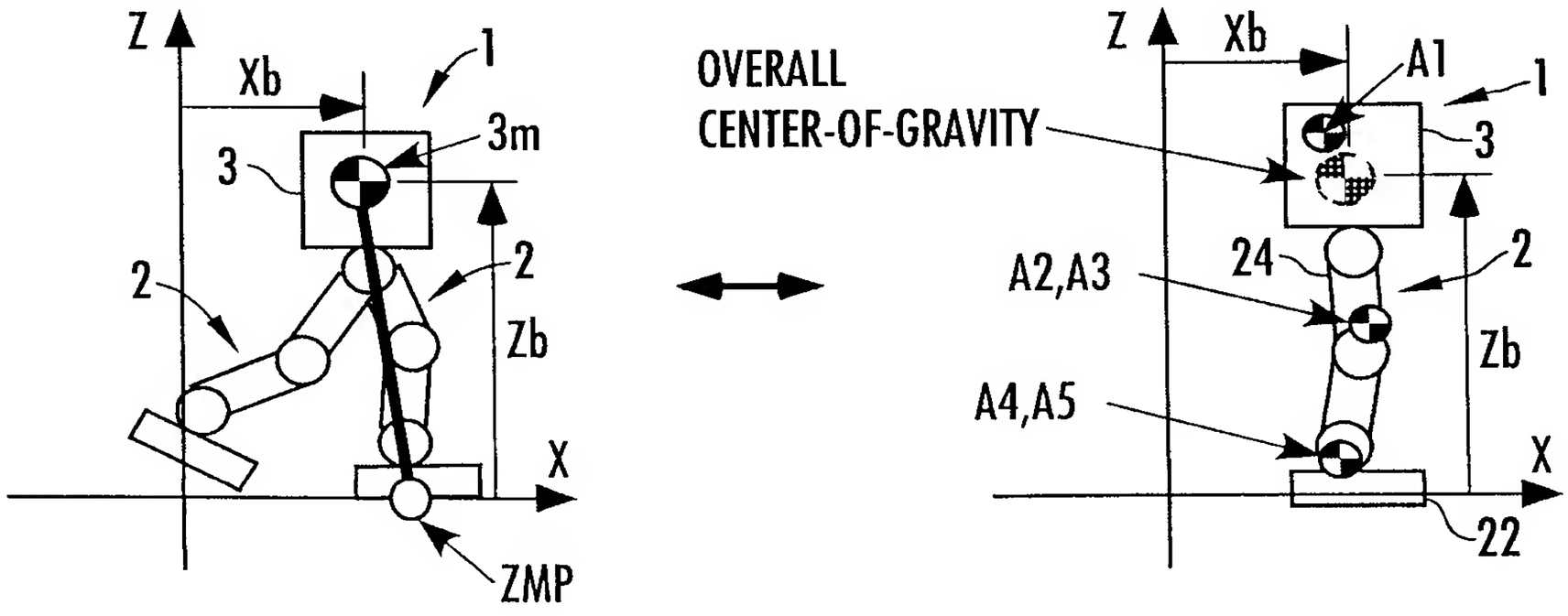


FIG.8

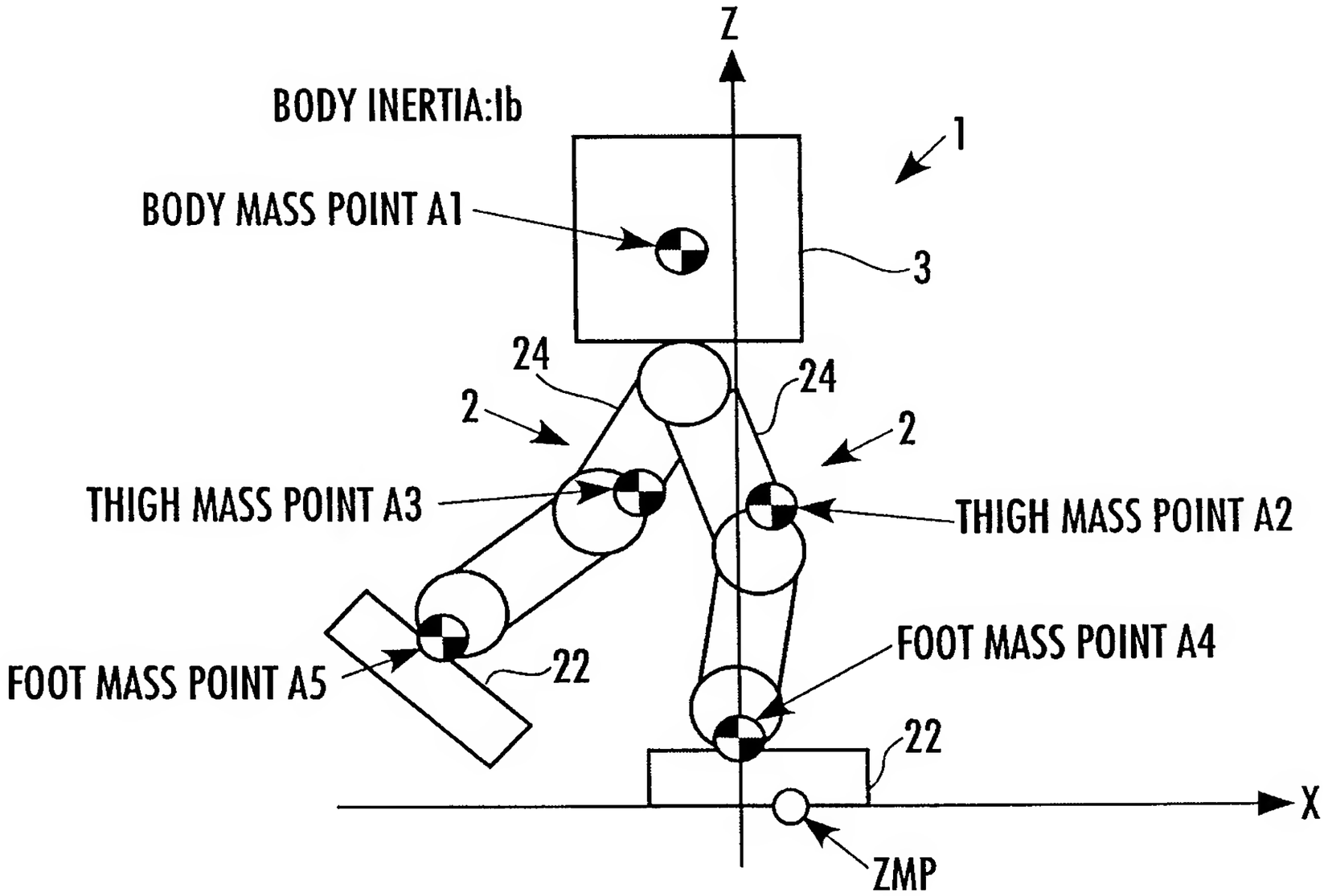

Z
BODY INERTIA:Ib
1
BODY MASS POINT A1
3
24
24
2
2
THIGH MASS POINT A3
THIGH MASS POINT A2
FOOT MASS POINT A4
FOOT MASS POINT A5
22
22
X
ZMP

FIG.9

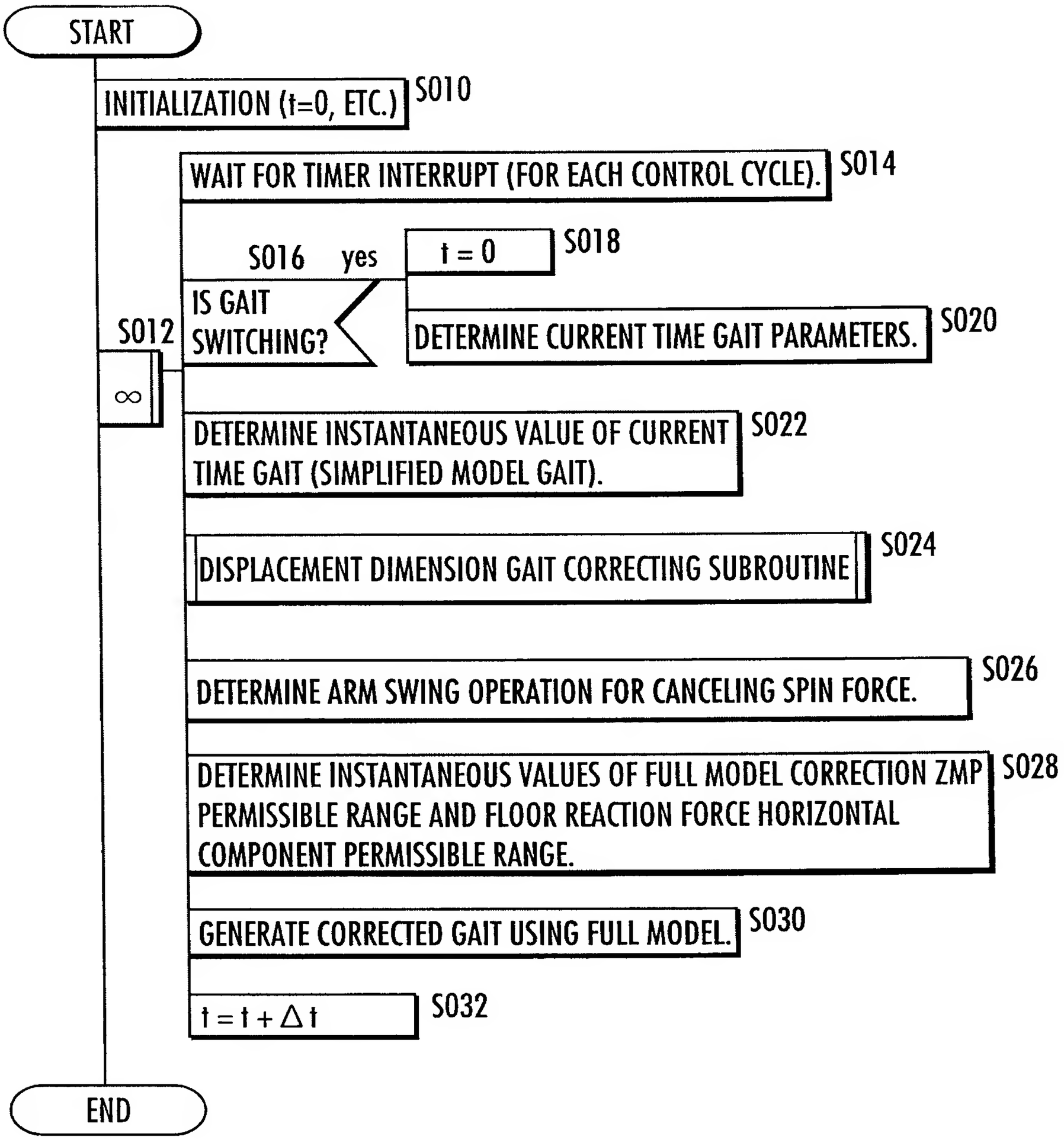

START
INITIALIZATION (t=0, ETC.)
S010
WAIT FOR TIMER INTERRUPT (FOR EACH CONTROL CYCLE).
S014
S016
yes
t = 0
S018
IS GAIT SWITCHING?
S012
∞
DETERMINE CURRENT TIME GAIT PARAMETERS.
S020
DETERMINE INSTANTANEOUS VALUE OF CURRENT TIME GAIT (SIMPLIFIED MODEL GAIT).
S022
DISPLACEMENT DIMENSION GAIT CORRECTING SUBROUTINE
S024
DETERMINE ARM SWING OPERATION FOR CANCELING SPIN FORCE.
S026
DETERMINE INSTANTANEOUS VALUES OF FULL MODEL CORRECTION ZMP PERMISSIBLE RANGE AND FLOOR REACTION FORCE HORIZONTAL COMPONENT PERMISSIBLE RANGE.
S028
GENERATE CORRECTED GAIT USING FULL MODEL.
S030
t = t + Δt
S032
END

FIG.10

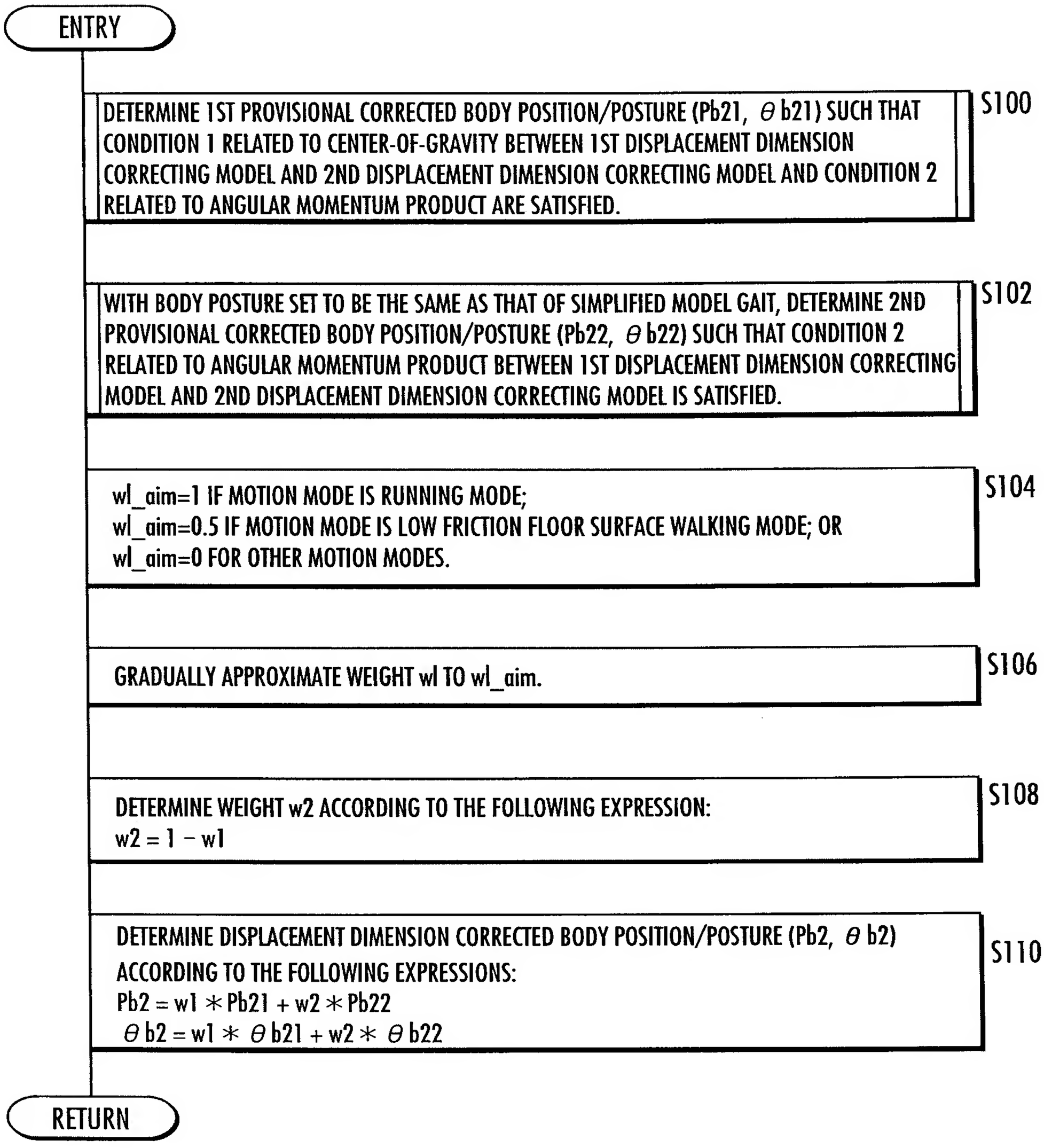

ENTRY
DETERMINE 1ST PROVISIONAL CORRECTED BODY POSITION/POSTURE (Pb21, θb21) SUCH THAT CONDITION 1 RELATED TO CENTER-OF-GRAVITY BETWEEN 1ST DISPLACEMENT DIMENSION CORRECTING MODEL AND 2ND DISPLACEMENT DIMENSION CORRECTING MODEL AND CONDITION 2 RELATED TO ANGULAR MOMENTUM PRODUCT ARE SATISFIED.
S100
WITH BODY POSTURE SET TO BE THE SAME AS THAT OF SIMPLIFIED MODEL GAIT, DETERMINE 2ND PROVISIONAL CORRECTED BODY POSITION/POSTURE (Pb22, θb22) SUCH THAT CONDITION 2 RELATED TO ANGULAR MOMENTUM PRODUCT BETWEEN 1ST DISPLACEMENT DIMENSION CORRECTING MODEL AND 2ND DISPLACEMENT DIMENSION CORRECTING MODEL IS SATISFIED.
S102
wl_aim=1 IF MOTION MODE IS RUNNING MODE;
wl_aim=0.5 IF MOTION MODE IS LOW FRICTION FLOOR SURFACE WALKING MODE; OR
wl_aim=0 FOR OTHER MOTION MODES.
S104
GRADUALLY APPROXIMATE WEIGHT wl TO wl_aim.
S106
DETERMINE WEIGHT w2 ACCORDING TO THE FOLLOWING EXPRESSION:
w2 = 1 − w1
S108
DETERMINE DISPLACEMENT DIMENSION CORRECTED BODY POSITION/POSTURE (Pb2, θb2) ACCORDING TO THE FOLLOWING EXPRESSIONS:
Pb2 = w1 * Pb21 + w2 * Pb22
θb2 = w1 * θb21 + w2 * θb22
S110
RETURN

FIG.11

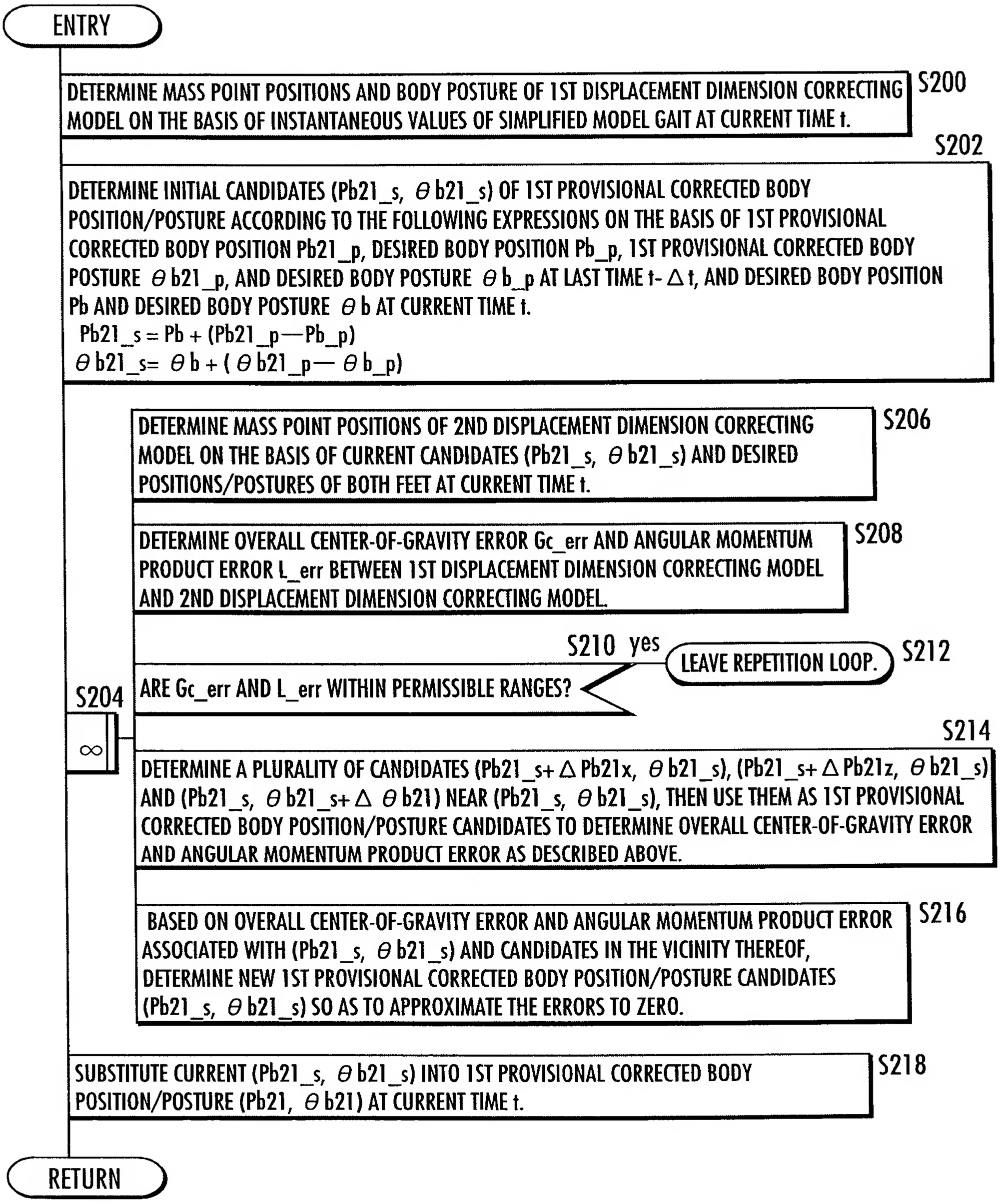

ENTRY
DETERMINE MASS POINT POSITIONS AND BODY POSTURE OF 1ST DISPLACEMENT DIMENSION CORRECTING MODEL ON THE BASIS OF INSTANTANEOUS VALUES OF SIMPLIFIED MODEL GAIT AT CURRENT TIME t.
S200
S202
DETERMINE INITIAL CANDIDATES (Pb21_s, θb21_s) OF 1ST PROVISIONAL CORRECTED BODY POSITION/POSTURE ACCORDING TO THE FOLLOWING EXPRESSIONS ON THE BASIS OF 1ST PROVISIONAL CORRECTED BODY POSITION Pb21_p, DESIRED BODY POSITION Pb_p, 1ST PROVISIONAL CORRECTED BODY POSTURE θb21_p, AND DESIRED BODY POSTURE θb_p AT LAST TIME t-Δt, AND DESIRED BODY POSITION Pb AND DESIRED BODY POSTURE θb AT CURRENT TIME t.
Pb21_s = Pb + (Pb21_p—Pb_p)
θb21_s= θb + (θb21_p— θb_p)
DETERMINE MASS POINT POSITIONS OF 2ND DISPLACEMENT DIMENSION CORRECTING MODEL ON THE BASIS OF CURRENT CANDIDATES (Pb21_s, θb21_s) AND DESIRED POSITIONS/POSTURES OF BOTH FEET AT CURRENT TIME t.
S206
DETERMINE OVERALL CENTER-OF-GRAVITY ERROR Gc_err AND ANGULAR MOMENTUM PRODUCT ERROR L_err BETWEEN 1ST DISPLACEMENT DIMENSION CORRECTING MODEL AND 2ND DISPLACEMENT DIMENSION CORRECTING MODEL.
S208
S210 yes
ARE Gc_err AND L_err WITHIN PERMISSIBLE RANGES?
LEAVE REPETITION LOOP.
S212
S204
∞
DETERMINE A PLURALITY OF CANDIDATES (Pb21_s+Δ Pb21x, θb21_s), (Pb21_s+Δ Pb21z, θb21_s) AND (Pb21_s, θb21_s+Δ θb21) NEAR (Pb21_s, θb21_s), THEN USE THEM AS 1ST PROVISIONAL CORRECTED BODY POSITION/POSTURE CANDIDATES TO DETERMINE OVERALL CENTER-OF-GRAVITY ERROR AND ANGULAR MOMENTUM PRODUCT ERROR AS DESCRIBED ABOVE.
S214
BASED ON OVERALL CENTER-OF-GRAVITY ERROR AND ANGULAR MOMENTUM PRODUCT ERROR ASSOCIATED WITH (Pb21_s, θb21_s) AND CANDIDATES IN THE VICINITY THEREOF, DETERMINE NEW 1ST PROVISIONAL CORRECTED BODY POSITION/POSTURE CANDIDATES (Pb21_s, θb21_s) SO AS TO APPROXIMATE THE ERRORS TO ZERO.
S216
SUBSTITUTE CURRENT (Pb21_s, θb21_s) INTO 1ST PROVISIONAL CORRECTED BODY POSITION/POSTURE (Pb21, θb21) AT CURRENT TIME t.
S218
RETURN

FIG.12

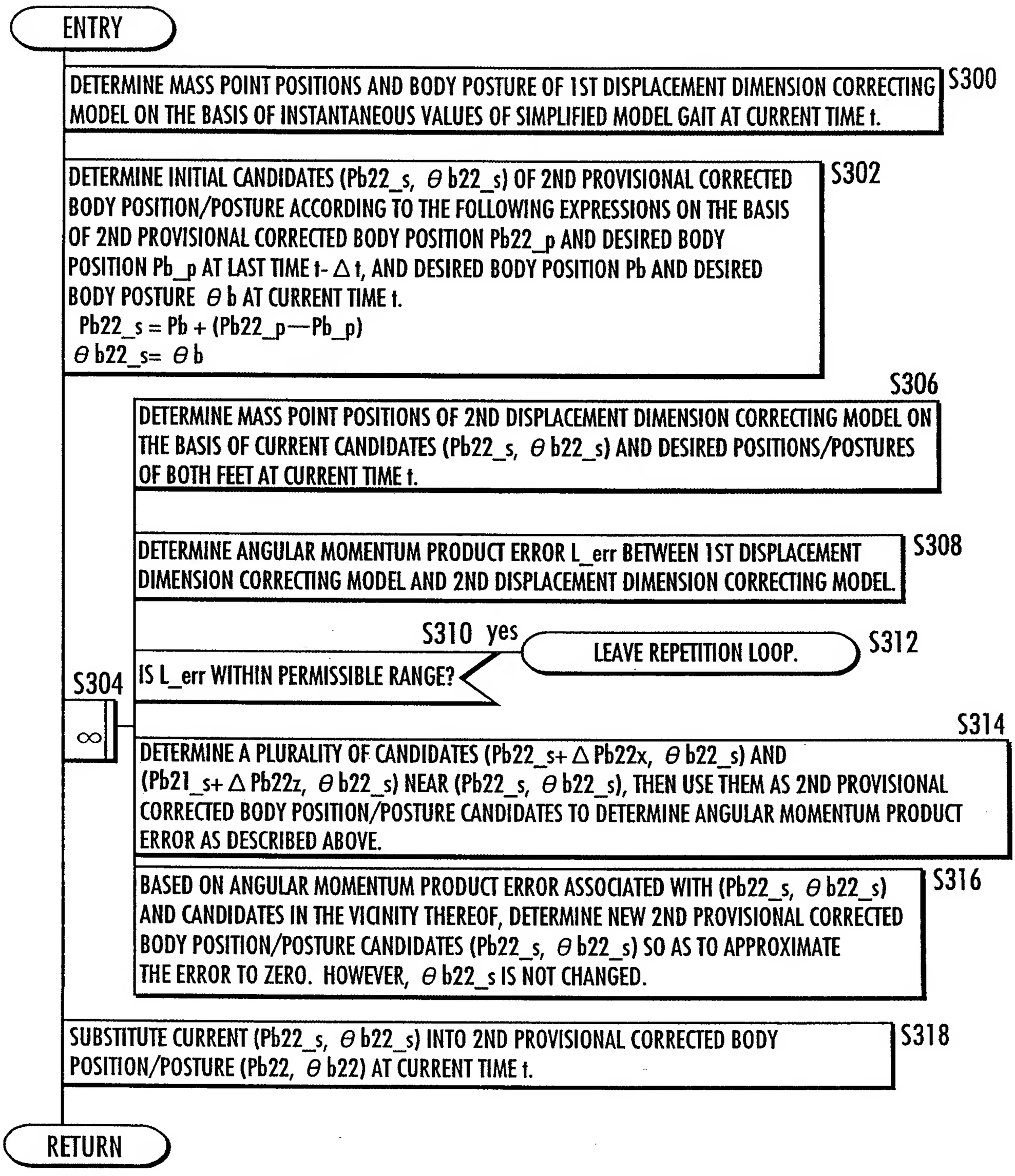

ENTRY
DETERMINE MASS POINT POSITIONS AND BODY POSTURE OF 1ST DISPLACEMENT DIMENSION CORRECTING MODEL ON THE BASIS OF INSTANTANEOUS VALUES OF SIMPLIFIED MODEL GAIT AT CURRENT TIME t.
S300
DETERMINE INITIAL CANDIDATES (Pb22_s, θb22_s) OF 2ND PROVISIONAL CORRECTED BODY POSITION/POSTURE ACCORDING TO THE FOLLOWING EXPRESSIONS ON THE BASIS OF 2ND PROVISIONAL CORRECTED BODY POSITION Pb22_p AND DESIRED BODY POSITION Pb_p AT LAST TIME t- Δt, AND DESIRED BODY POSITION Pb AND DESIRED BODY POSTURE θb AT CURRENT TIME t.
Pb22_s = Pb + (Pb22_p—Pb_p)
θb22_s= θb
S302
S306
DETERMINE MASS POINT POSITIONS OF 2ND DISPLACEMENT DIMENSION CORRECTING MODEL ON THE BASIS OF CURRENT CANDIDATES (Pb22_s, θb22_s) AND DESIRED POSITIONS/POSTURES OF BOTH FEET AT CURRENT TIME t.
DETERMINE ANGULAR MOMENTUM PRODUCT ERROR L_err BETWEEN 1ST DISPLACEMENT DIMENSION CORRECTING MODEL AND 2ND DISPLACEMENT DIMENSION CORRECTING MODEL.
S308
S310 yes
LEAVE REPETITION LOOP.
S312
IS L_err WITHIN PERMISSIBLE RANGE?
S304
∞
S314
DETERMINE A PLURALITY OF CANDIDATES (Pb22_s+ Δ Pb22x, θb22_s) AND (Pb21_s+ Δ Pb22z, θb22_s) NEAR (Pb22_s, θb22_s), THEN USE THEM AS 2ND PROVISIONAL CORRECTED BODY POSITION/POSTURE CANDIDATES TO DETERMINE ANGULAR MOMENTUM PRODUCT ERROR AS DESCRIBED ABOVE.
BASED ON ANGULAR MOMENTUM PRODUCT ERROR ASSOCIATED WITH (Pb22_s, θb22_s) AND CANDIDATES IN THE VICINITY THEREOF, DETERMINE NEW 2ND PROVISIONAL CORRECTED BODY POSITION/POSTURE CANDIDATES (Pb22_s, θb22_s) SO AS TO APPROXIMATE THE ERROR TO ZERO. HOWEVER, θb22_s IS NOT CHANGED.
S316
SUBSTITUTE CURRENT (Pb22_s, θb22_s) INTO 2ND PROVISIONAL CORRECTED BODY POSITION/POSTURE (Pb22, θb22) AT CURRENT TIME t.
S318
RETURN

FIG.13

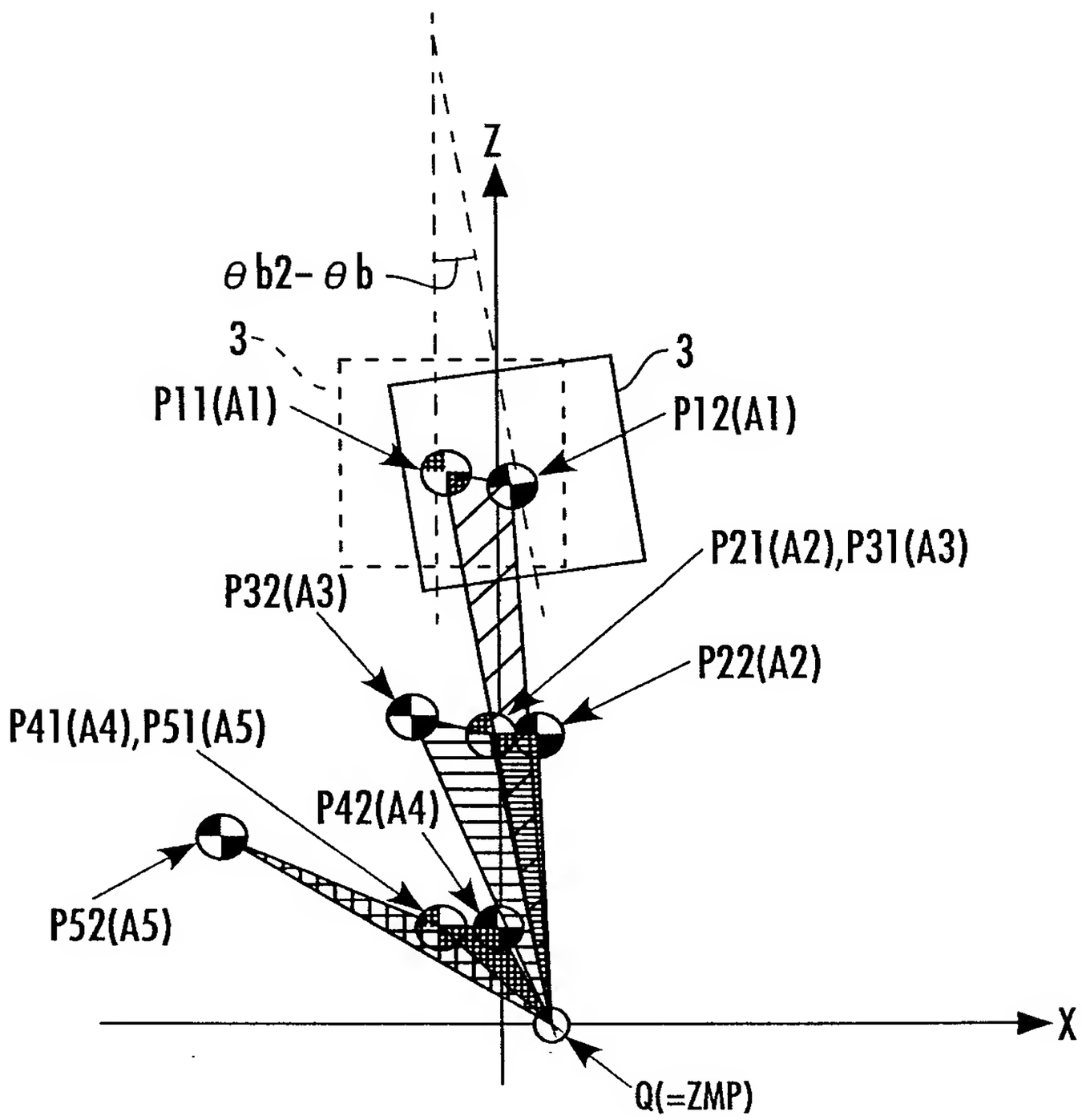

Z
θb2-θb
3
3
P11(A1)
P12(A1)
P21(A2),P31(A3)
P32(A3)
P22(A2)
P41(A4),P51(A5)
P42(A4)
P52(A5)
X
Q(=ZMP)

FIG.14

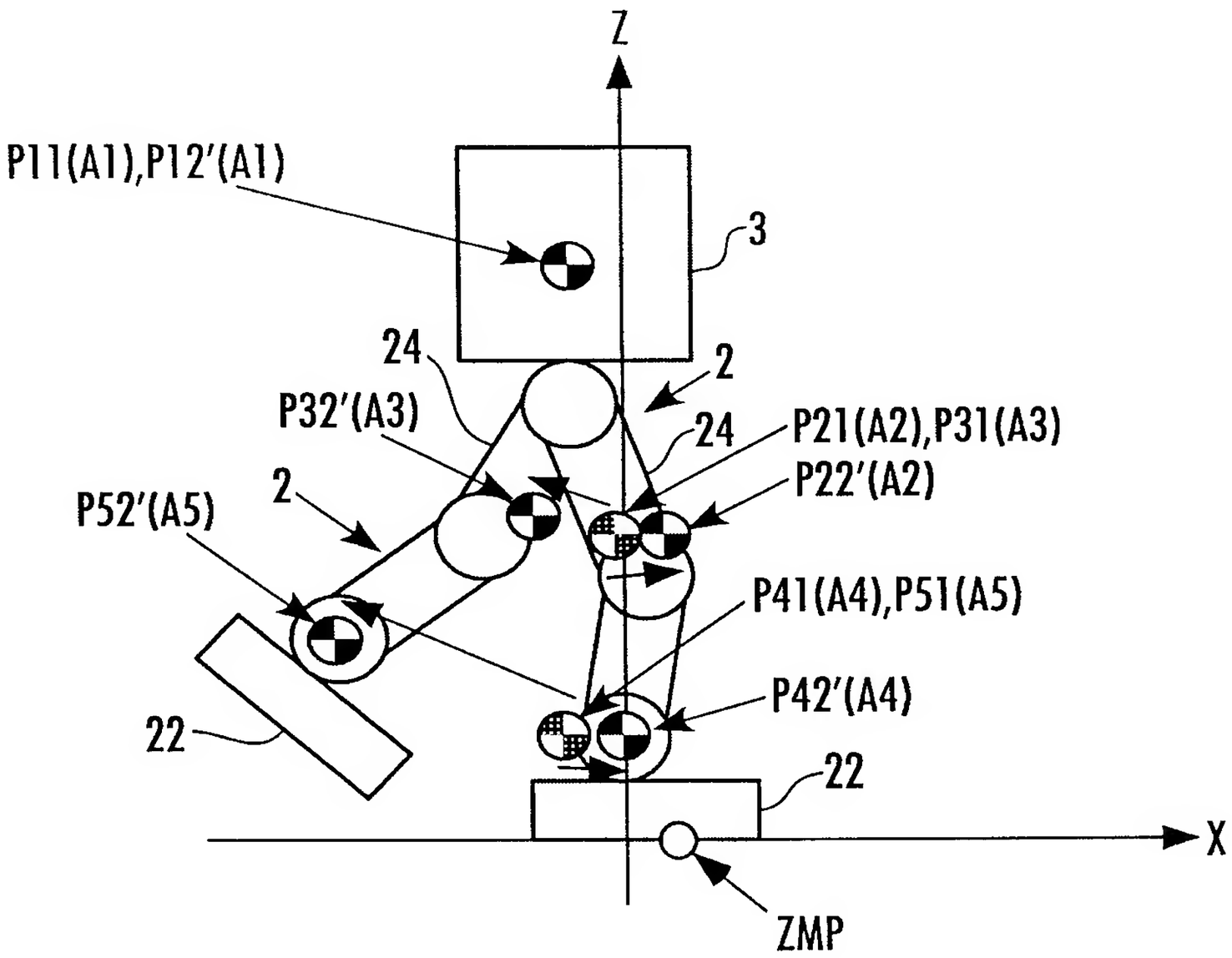

Z
P11(A1),P12'(A1)
3
24
2
P32'(A3)
24
P21(A2),P31(A3)
P22'(A2)
2
P52'(A5)
P41(A4),P51(A5)
P42'(A4)
22
22
X
ZMP

FIG.15

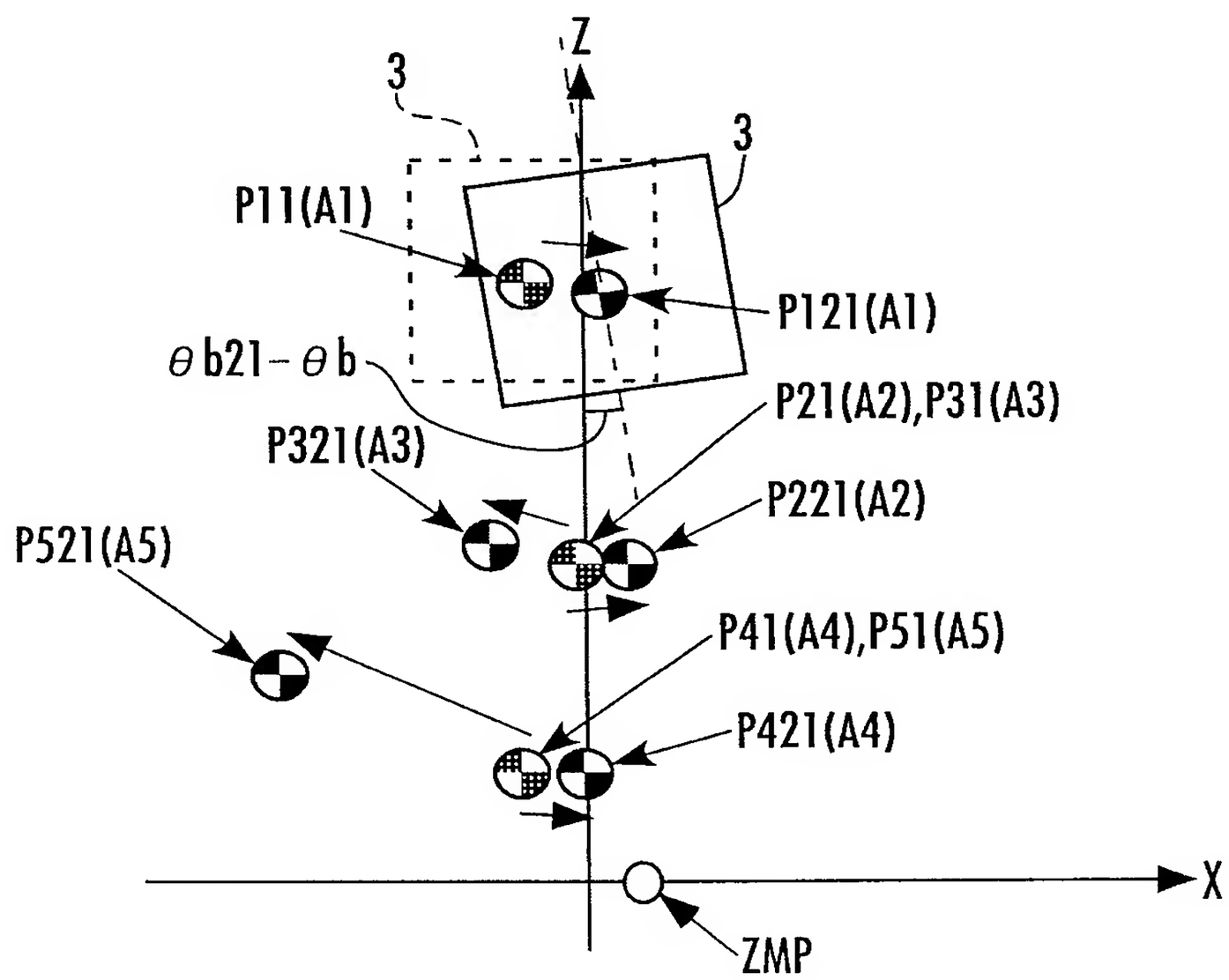

Z
3
3
P11(A1)
P121(A1)
θb21−θb
P21(A2),P31(A3)
P321(A3)
P221(A2)
P521(A5)
P41(A4),P51(A5)
P421(A4)
X
ZMP

FIG.16

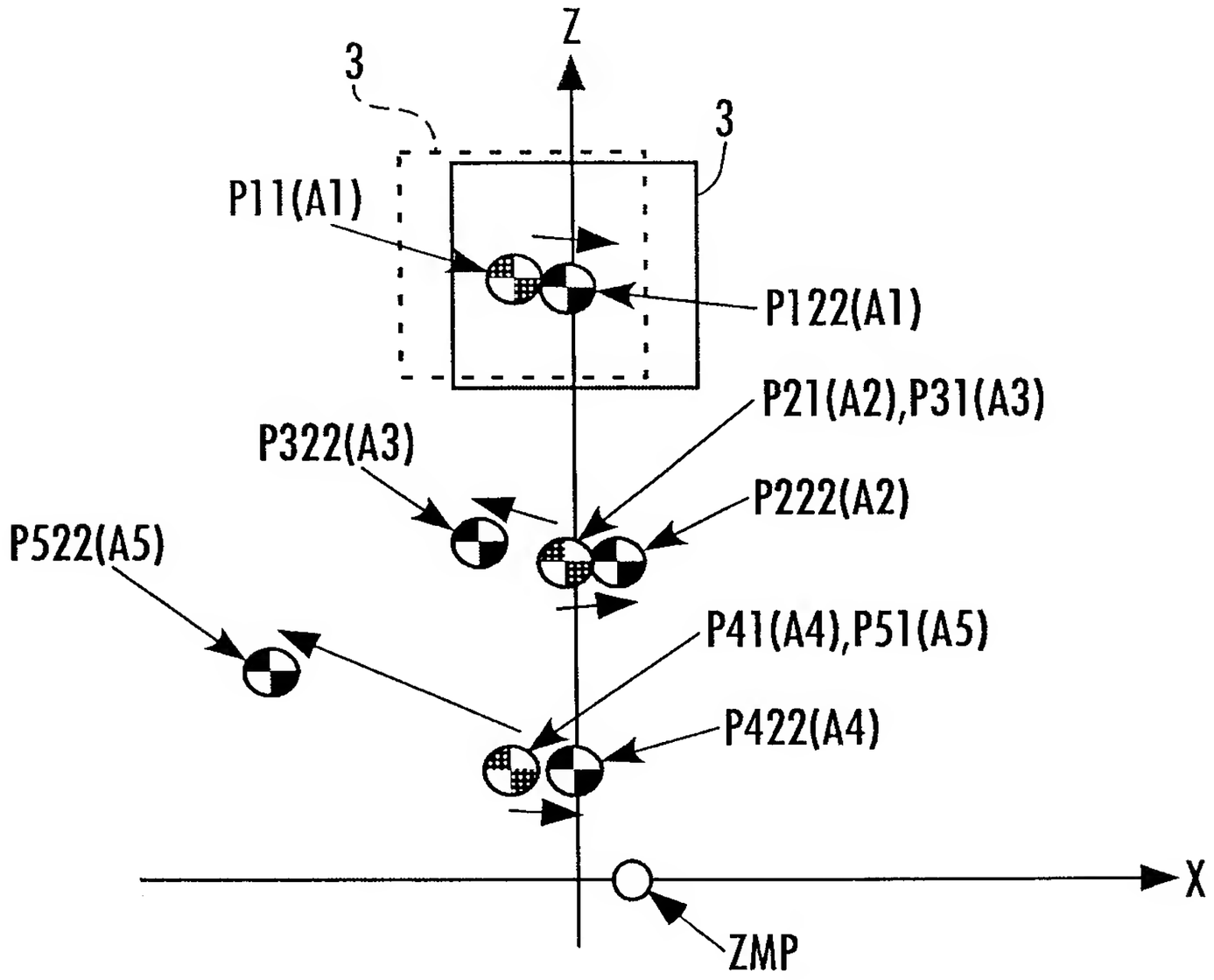

Z
3
3
P11(A1)
P122(A1)
P21(A2),P31(A3)
P322(A3)
P222(A2)
P522(A5)
P41(A4),P51(A5)
P422(A4)
X
ZMP

FIG.17

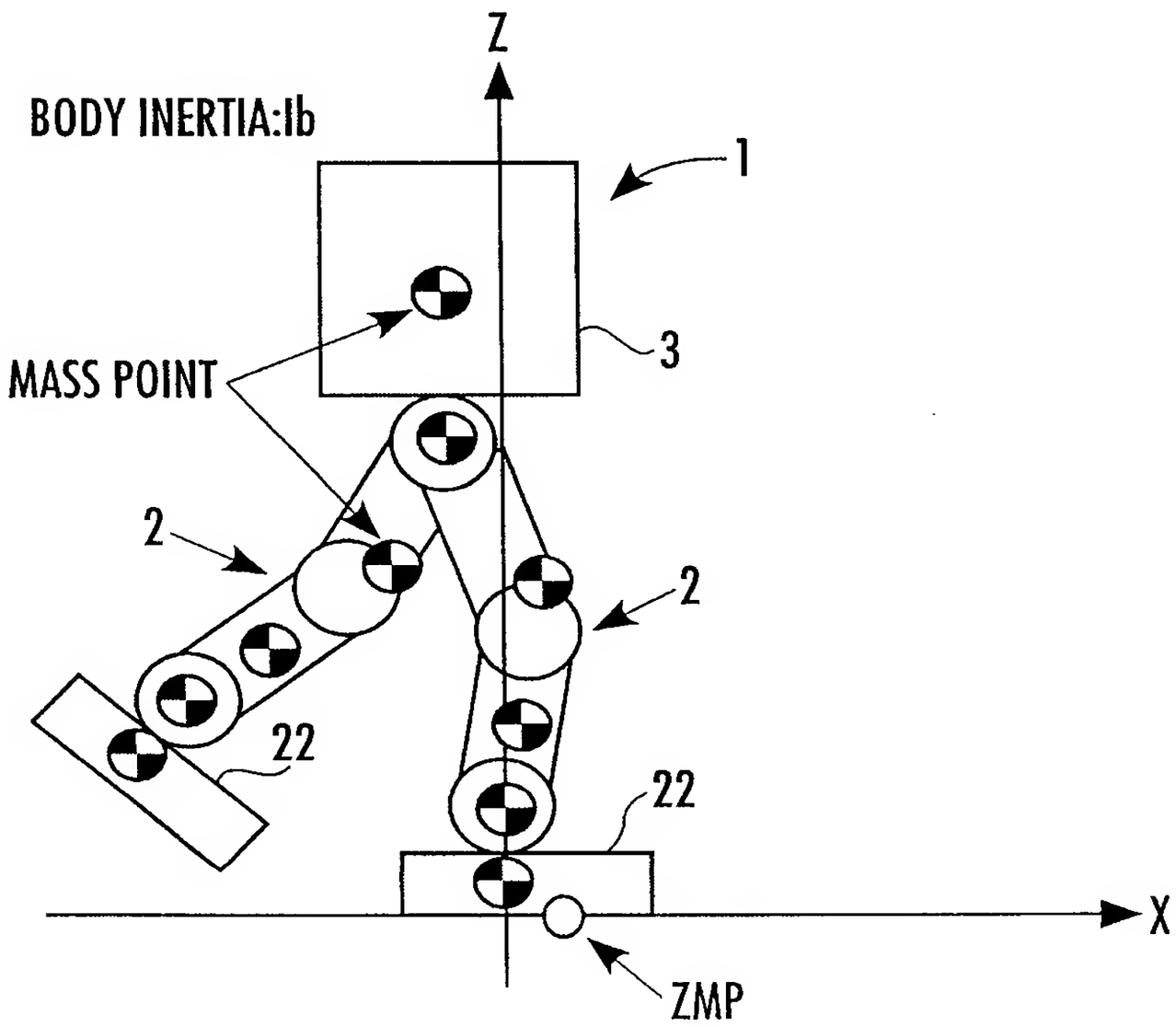

Z
BODY INERTIA:Ib
1
MASS POINT
3
2
2
22
22
X
ZMP

FIG.18

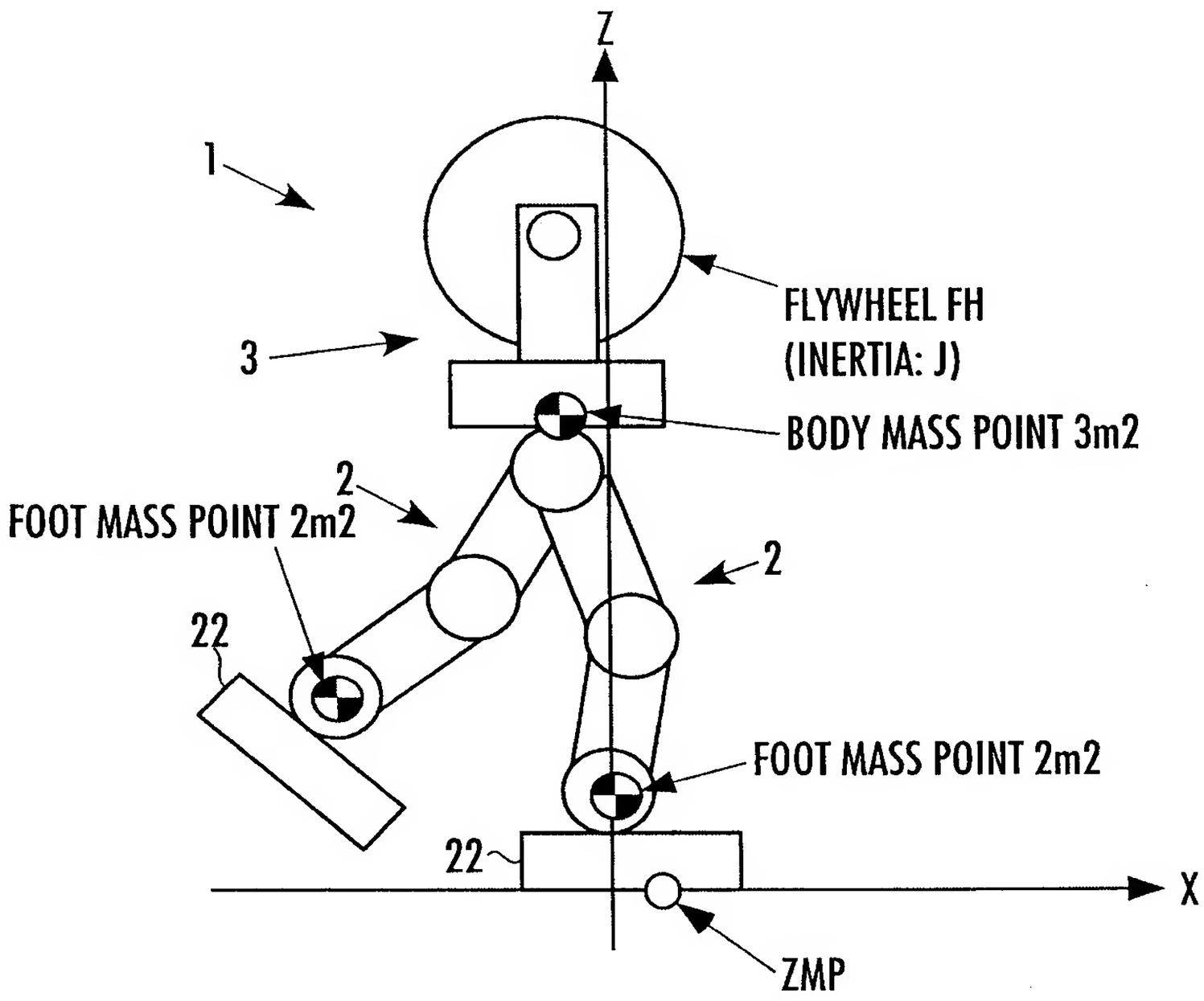

Z
1
FLYWHEEL FH
(INERTIA: J)
3
BODY MASS POINT 3m2
2
FOOT MASS POINT 2m2
2
22
FOOT MASS POINT 2m2
22
X
ZMP

FIG.19

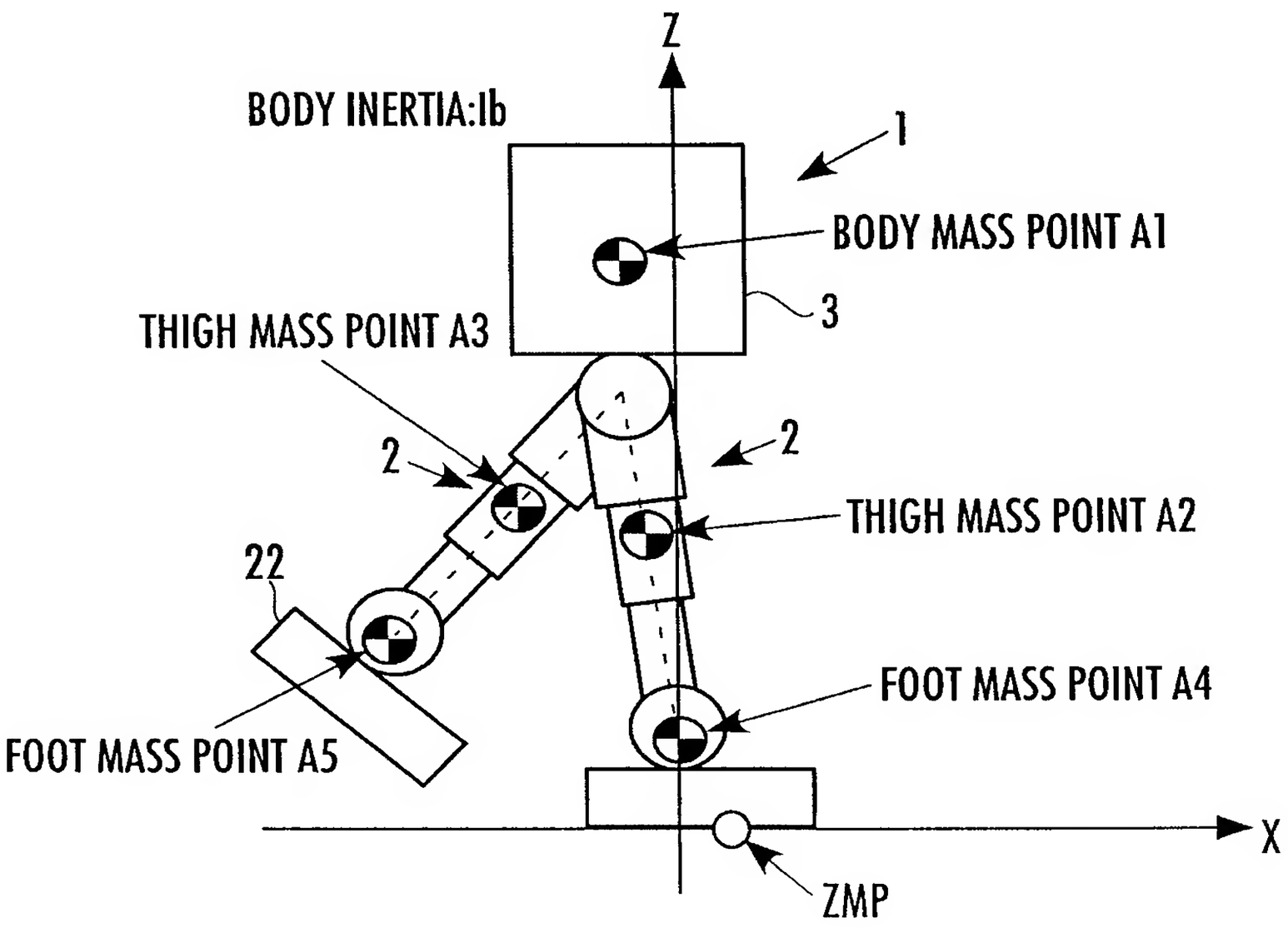

Z
BODY INERTIA:Ib
1
BODY MASS POINT A1
3
THIGH MASS POINT A3
2
2
THIGH MASS POINT A2
22
FOOT MASS POINT A4
FOOT MASS POINT A5
X
ZMP

FIG.20

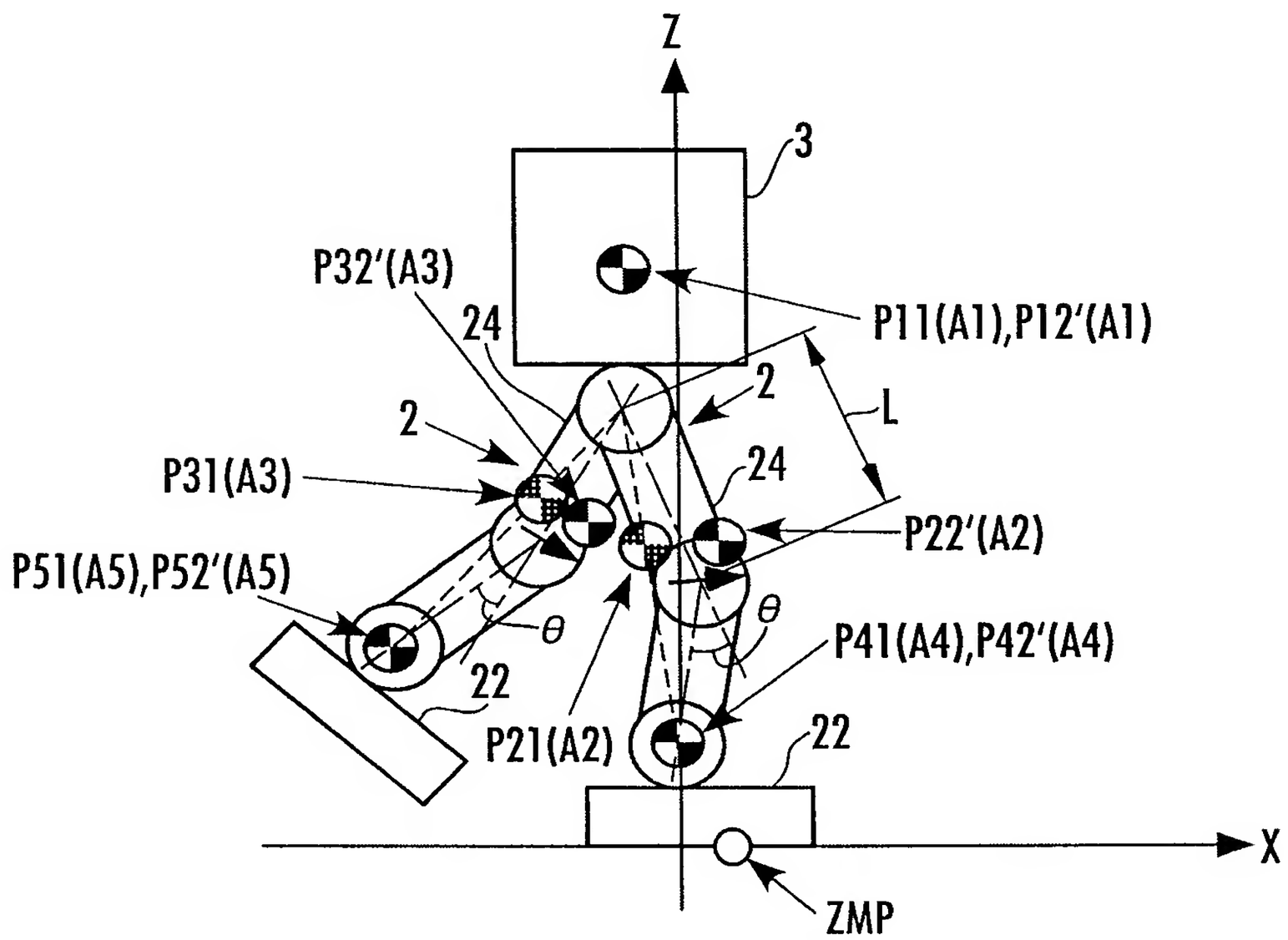

Z
3
P32'(A3)
24
P11(A1),P12'(A1)
2
2
L
P31(A3)
24
P22'(A2)
P51(A5),P52'(A5)
θ
θ
P41(A4),P42'(A4)
22
P21(A2)
22
X
ZMP

FIG.21

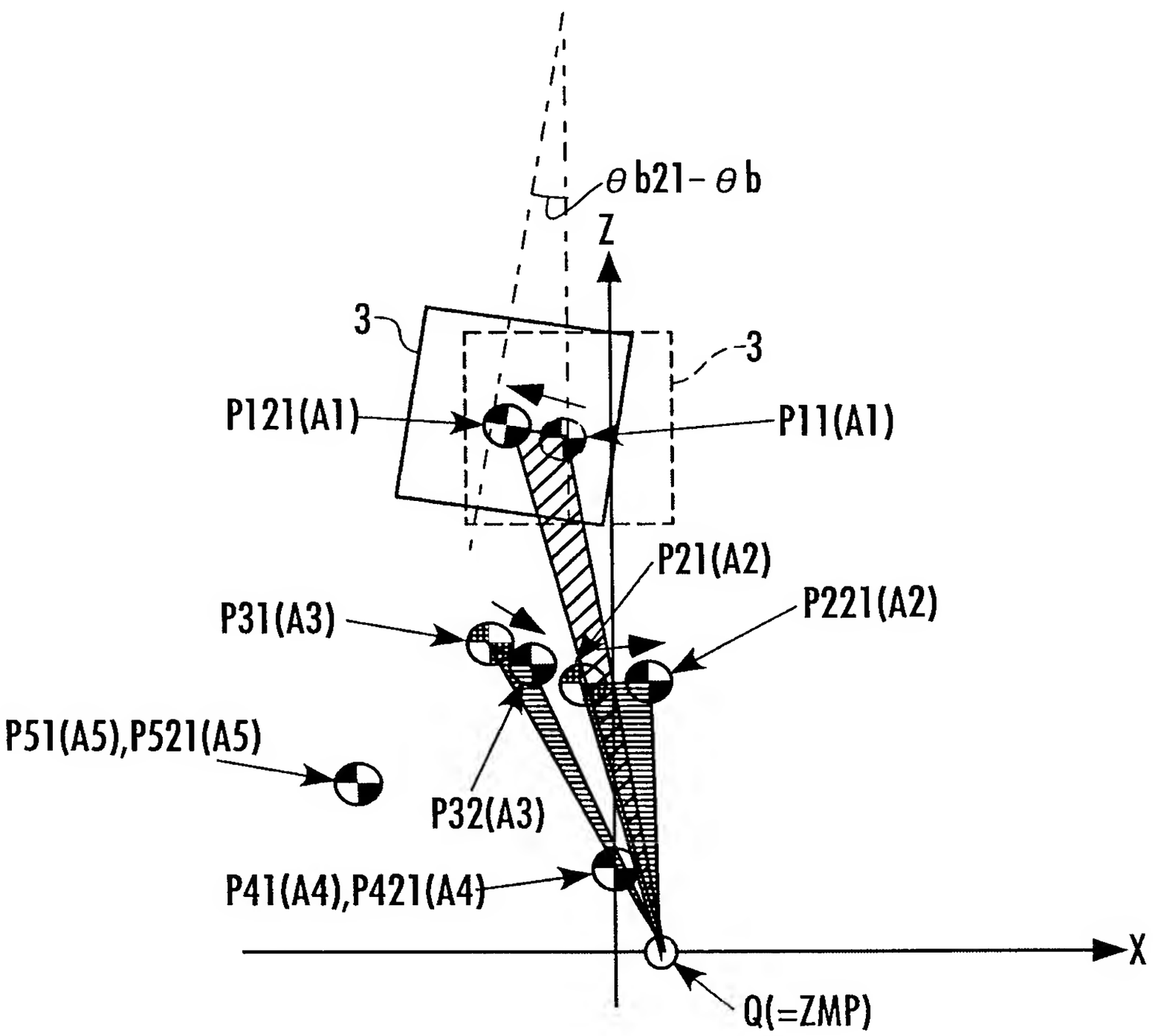

θb21−θb
Z
3
3
P121(A1)
P11(A1)
P21(A2)
P31(A3)
P221(A2)
P51(A5),P521(A5)
P32(A3)
P41(A4),P421(A4)
X
Q(=ZMP)

FIG.22

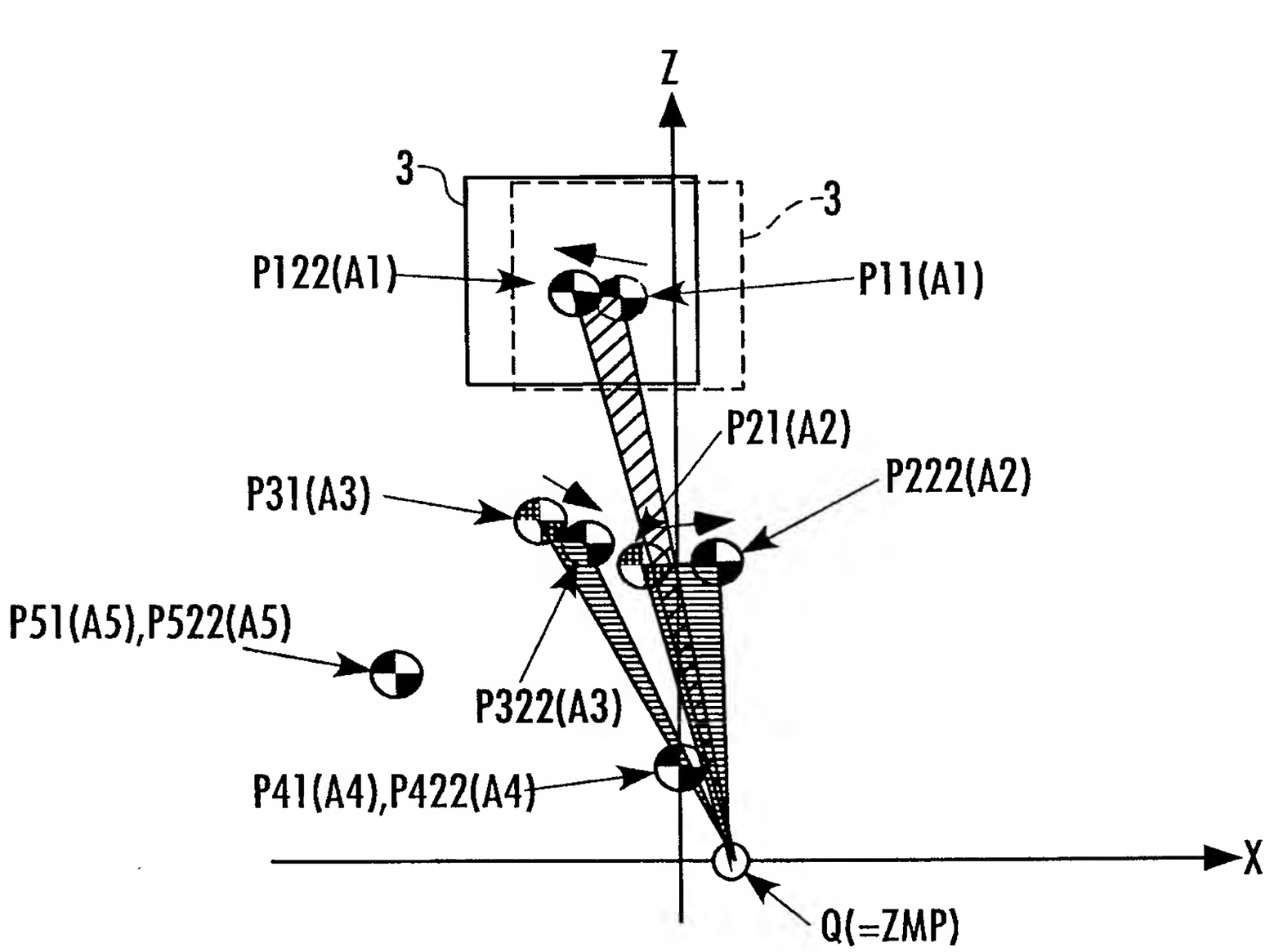

Z
3
-3
P122(A1)
P11(A1)
P21(A2)
P31(A3)
P222(A2)
P51(A5),P522(A5)
P322(A3)
P41(A4),P422(A4)
X
Q(=ZMP)

FIG.23

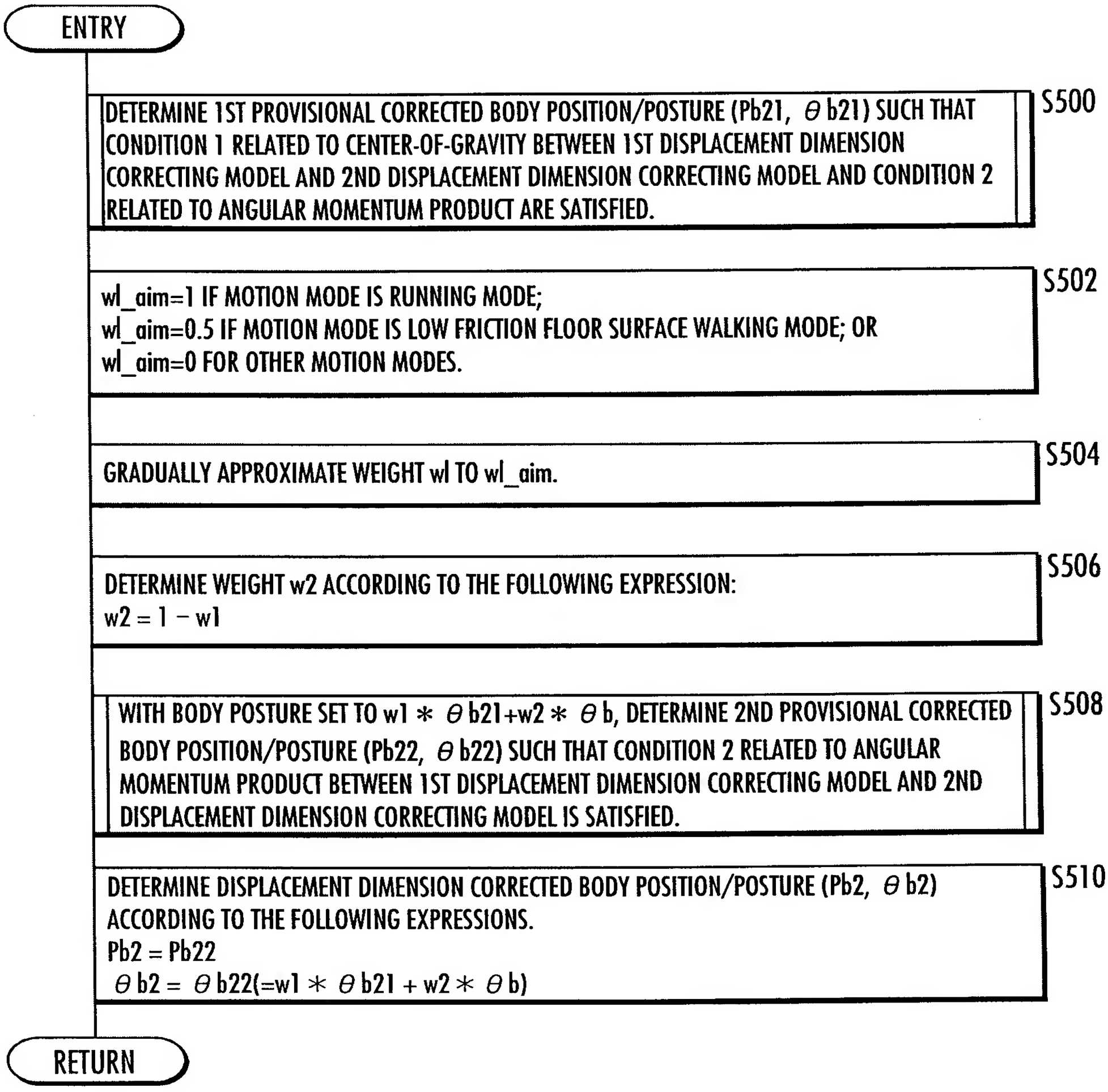

ENTRY
DETERMINE 1ST PROVISIONAL CORRECTED BODY POSITION/POSTURE (Pb21, θb21) SUCH THAT CONDITION 1 RELATED TO CENTER-OF-GRAVITY BETWEEN 1ST DISPLACEMENT DIMENSION CORRECTING MODEL AND 2ND DISPLACEMENT DIMENSION CORRECTING MODEL AND CONDITION 2 RELATED TO ANGULAR MOMENTUM PRODUCT ARE SATISFIED.
S500
wl_aim=1 IF MOTION MODE IS RUNNING MODE;
wl_aim=0.5 IF MOTION MODE IS LOW FRICTION FLOOR SURFACE WALKING MODE; OR
wl_aim=0 FOR OTHER MOTION MODES.
S502
GRADUALLY APPROXIMATE WEIGHT wl TO wl_aim.
S504
DETERMINE WEIGHT w2 ACCORDING TO THE FOLLOWING EXPRESSION:
w2 = 1 − w1
S506
WITH BODY POSTURE SET TO w1 * θb21+w2 * θb, DETERMINE 2ND PROVISIONAL CORRECTED BODY POSITION/POSTURE (Pb22, θb22) SUCH THAT CONDITION 2 RELATED TO ANGULAR MOMENTUM PRODUCT BETWEEN 1ST DISPLACEMENT DIMENSION CORRECTING MODEL AND 2ND DISPLACEMENT DIMENSION CORRECTING MODEL IS SATISFIED.
S508
DETERMINE DISPLACEMENT DIMENSION CORRECTED BODY POSITION/POSTURE (Pb2, θb2) ACCORDING TO THE FOLLOWING EXPRESSIONS.
Pb2 = Pb22
θb2 = θb22(=w1 * θb21 + w2 * θb)
S510
RETURN

FIG.24

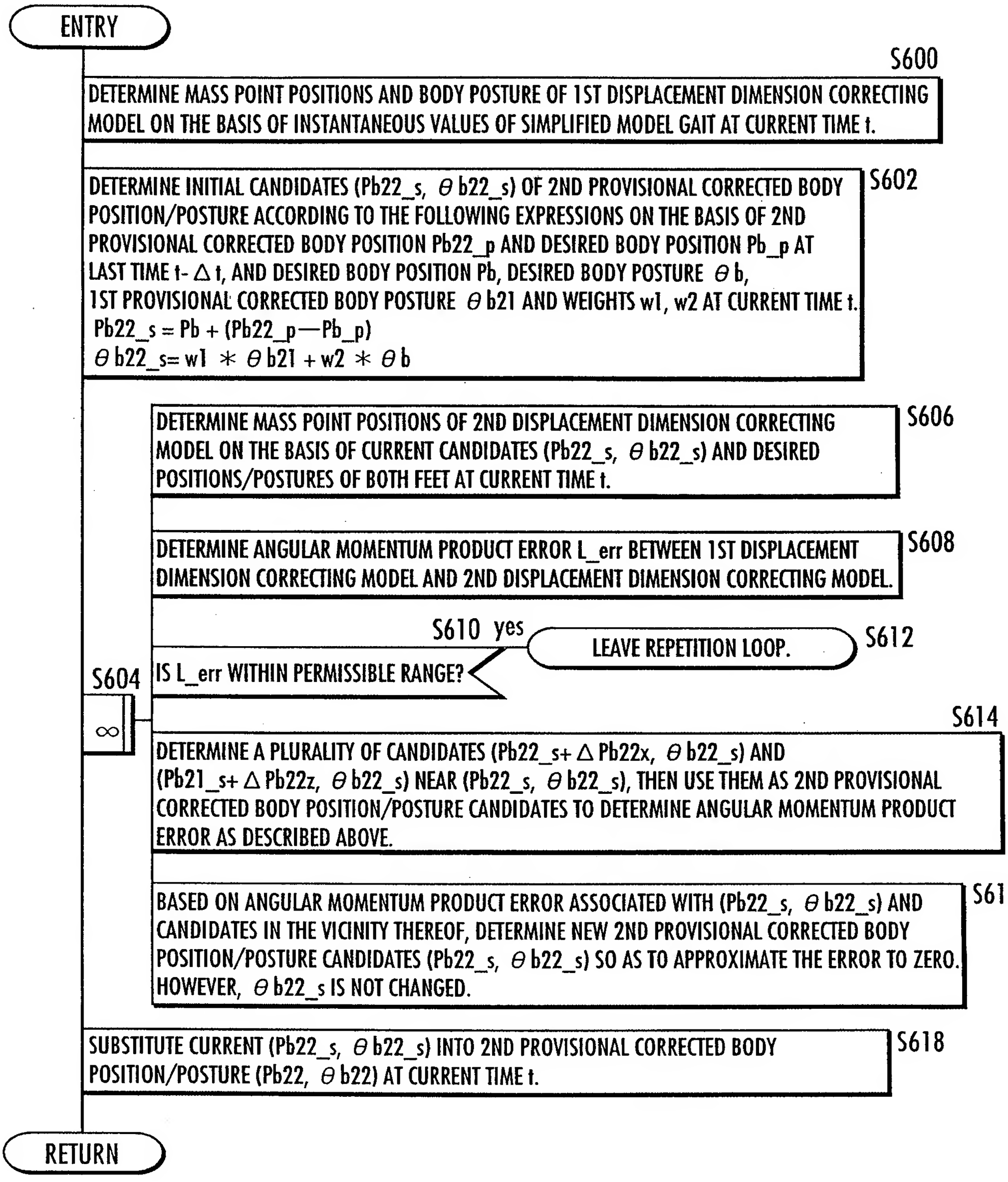

ENTRY
S600
DETERMINE MASS POINT POSITIONS AND BODY POSTURE OF 1ST DISPLACEMENT DIMENSION CORRECTING MODEL ON THE BASIS OF INSTANTANEOUS VALUES OF SIMPLIFIED MODEL GAIT AT CURRENT TIME t.
S602
DETERMINE INITIAL CANDIDATES (Pb22_s, θb22_s) OF 2ND PROVISIONAL CORRECTED BODY POSITION/POSTURE ACCORDING TO THE FOLLOWING EXPRESSIONS ON THE BASIS OF 2ND PROVISIONAL CORRECTED BODY POSITION Pb22_p AND DESIRED BODY POSITION Pb_p AT LAST TIME t- Δt, AND DESIRED BODY POSITION Pb, DESIRED BODY POSTURE θb, 1ST PROVISIONAL CORRECTED BODY POSTURE θb21 AND WEIGHTS w1, w2 AT CURRENT TIME t.
Pb22_s = Pb + (Pb22_p—Pb_p)
θb22_s= w1 * θb21 + w2 * θb
S606
DETERMINE MASS POINT POSITIONS OF 2ND DISPLACEMENT DIMENSION CORRECTING MODEL ON THE BASIS OF CURRENT CANDIDATES (Pb22_s, θb22_s) AND DESIRED POSITIONS/POSTURES OF BOTH FEET AT CURRENT TIME t.
S608
DETERMINE ANGULAR MOMENTUM PRODUCT ERROR L_err BETWEEN 1ST DISPLACEMENT DIMENSION CORRECTING MODEL AND 2ND DISPLACEMENT DIMENSION CORRECTING MODEL.
S610 yes
LEAVE REPETITION LOOP.
S612
S604
IS L_err WITHIN PERMISSIBLE RANGE?
∞
S614
DETERMINE A PLURALITY OF CANDIDATES (Pb22_s+ Δ Pb22x, θb22_s) AND (Pb21_s+ Δ Pb22z, θb22_s) NEAR (Pb22_s, θb22_s), THEN USE THEM AS 2ND PROVISIONAL CORRECTED BODY POSITION/POSTURE CANDIDATES TO DETERMINE ANGULAR MOMENTUM PRODUCT ERROR AS DESCRIBED ABOVE.
S616
BASED ON ANGULAR MOMENTUM PRODUCT ERROR ASSOCIATED WITH (Pb22_s, θb22_s) AND CANDIDATES IN THE VICINITY THEREOF, DETERMINE NEW 2ND PROVISIONAL CORRECTED BODY POSITION/POSTURE CANDIDATES (Pb22_s, θb22_s) SO AS TO APPROXIMATE THE ERROR TO ZERO. HOWEVER, θb22_s IS NOT CHANGED.
S618
SUBSTITUTE CURRENT (Pb22_s, θb22_s) INTO 2ND PROVISIONAL CORRECTED BODY POSITION/POSTURE (Pb22, θb22) AT CURRENT TIME t.
RETURN

FIG.25

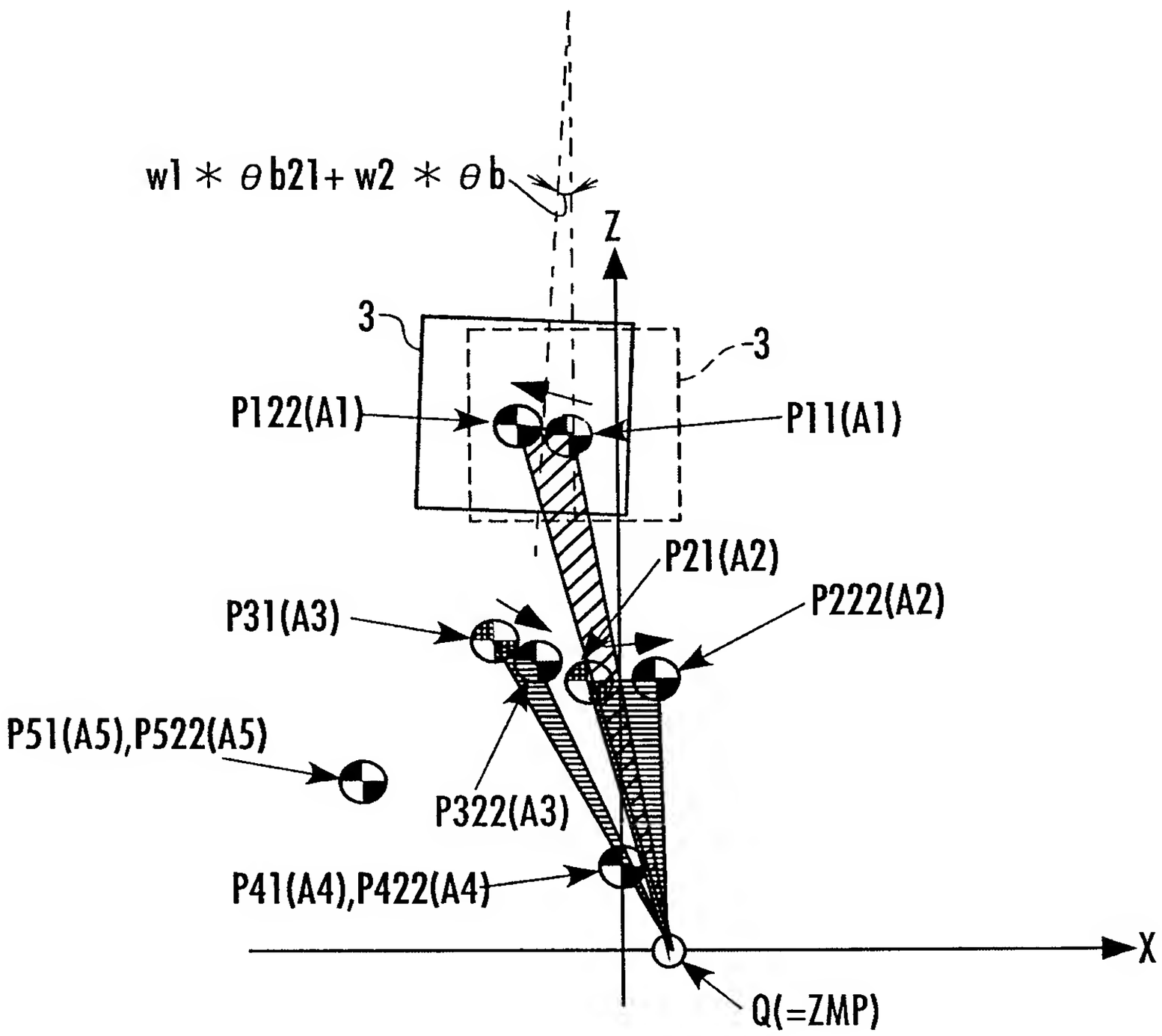

w1 * θb21+ w2 * θb
Z
3
-3
P122(A1)
P11(A1)
P21(A2)
P31(A3)
P222(A2)
P51(A5),P522(A5)
P322(A3)
P41(A4),P422(A4)
X
Q(=ZMP)

FIG.26(a)

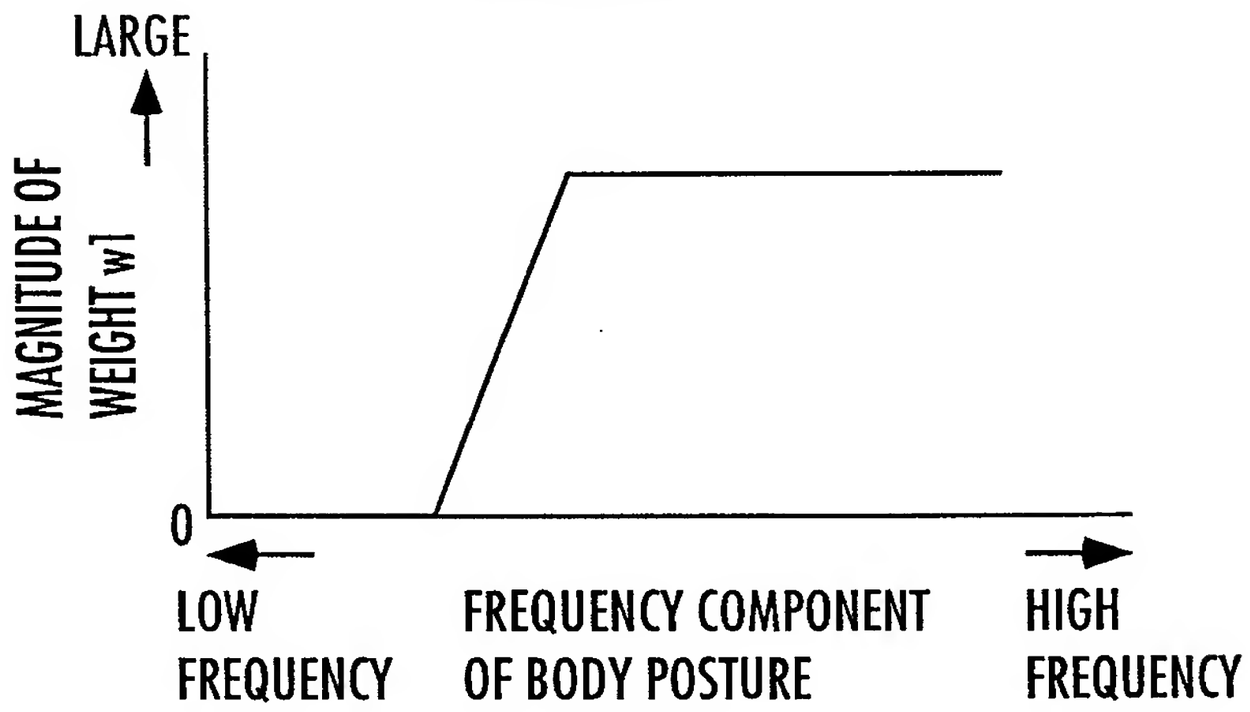


FIG.26(b)

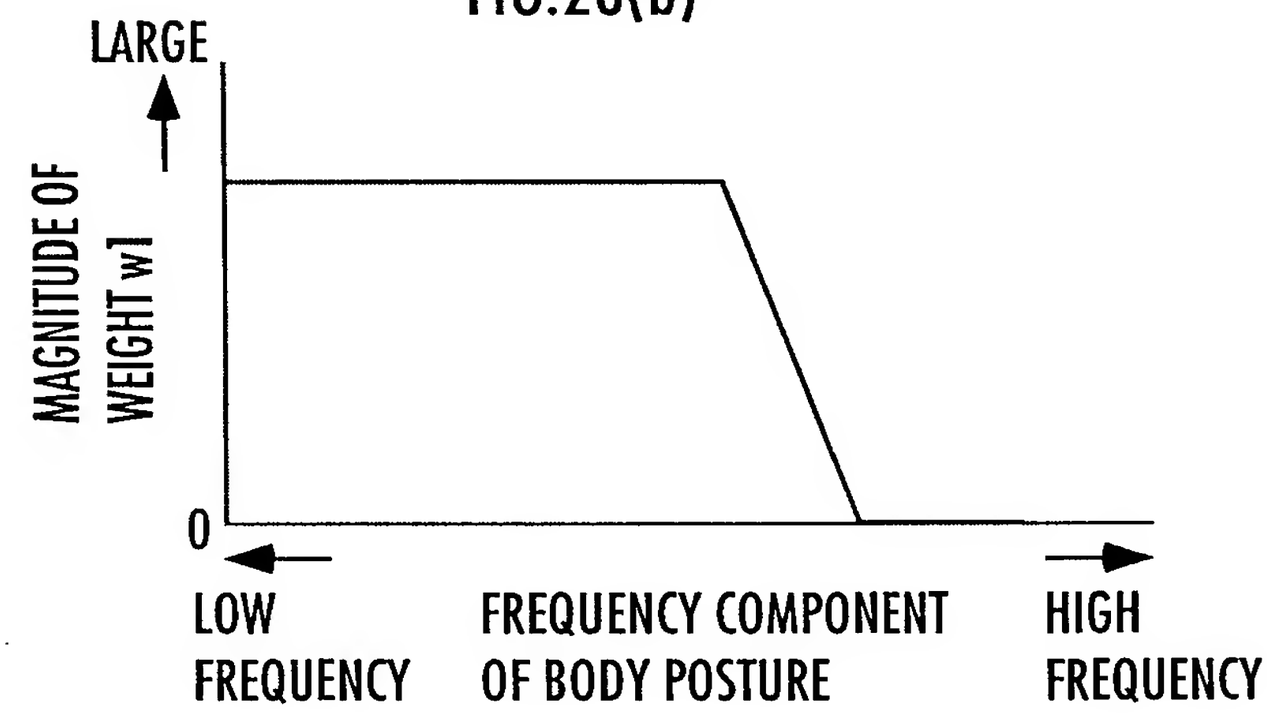
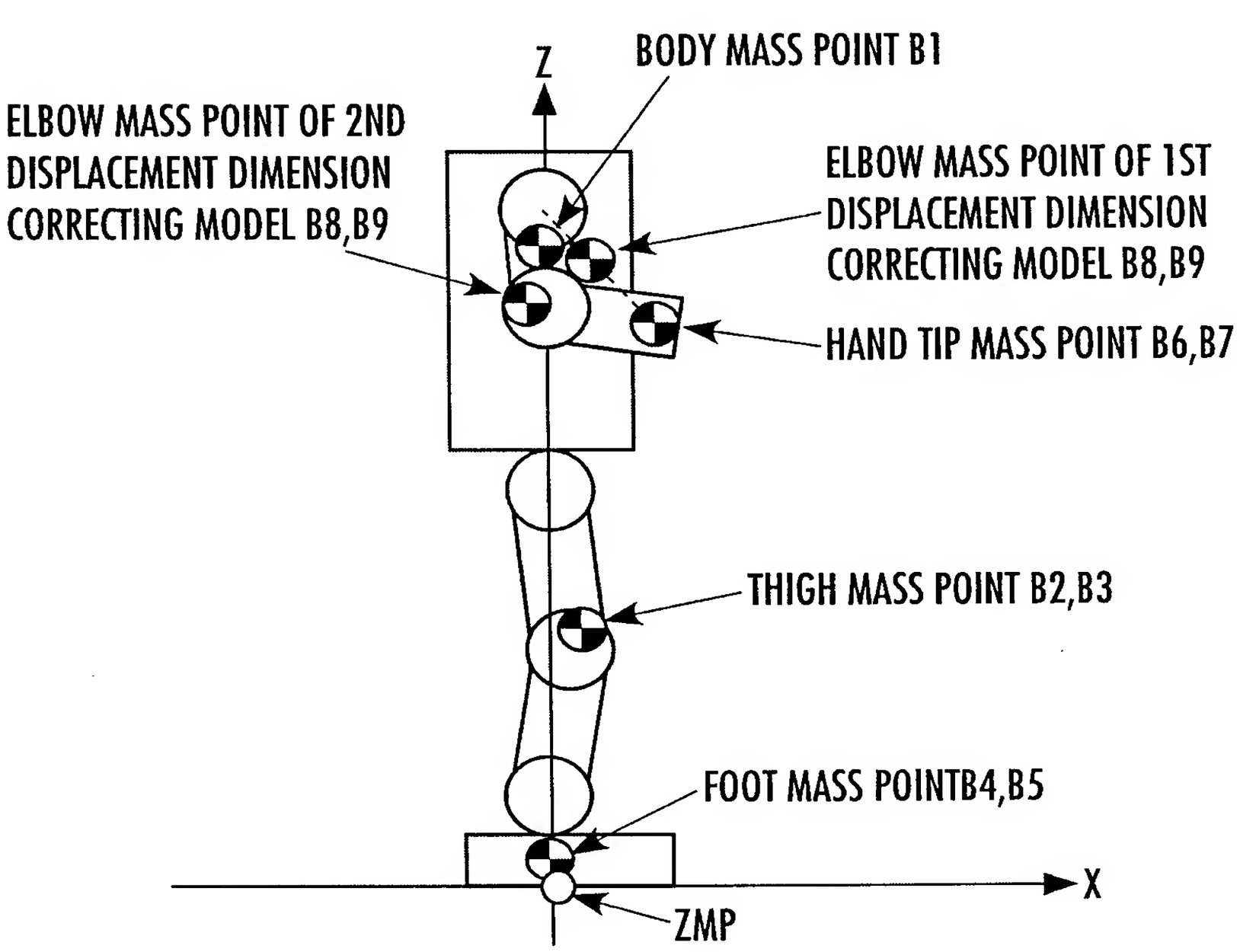


FIG.27


Z
BODY MASS POINT B1
ELBOW MASS POINT OF 2ND DISPLACEMENT DIMENSION CORRECTING MODEL B8,B9
ELBOW MASS POINT OF 1ST DISPLACEMENT DIMENSION CORRECTING MODEL B8,B9
HAND TIP MASS POINT B6,B7
THIGH MASS POINT B2,B3
FOOT MASS POINTB4,B5
X
ZMP